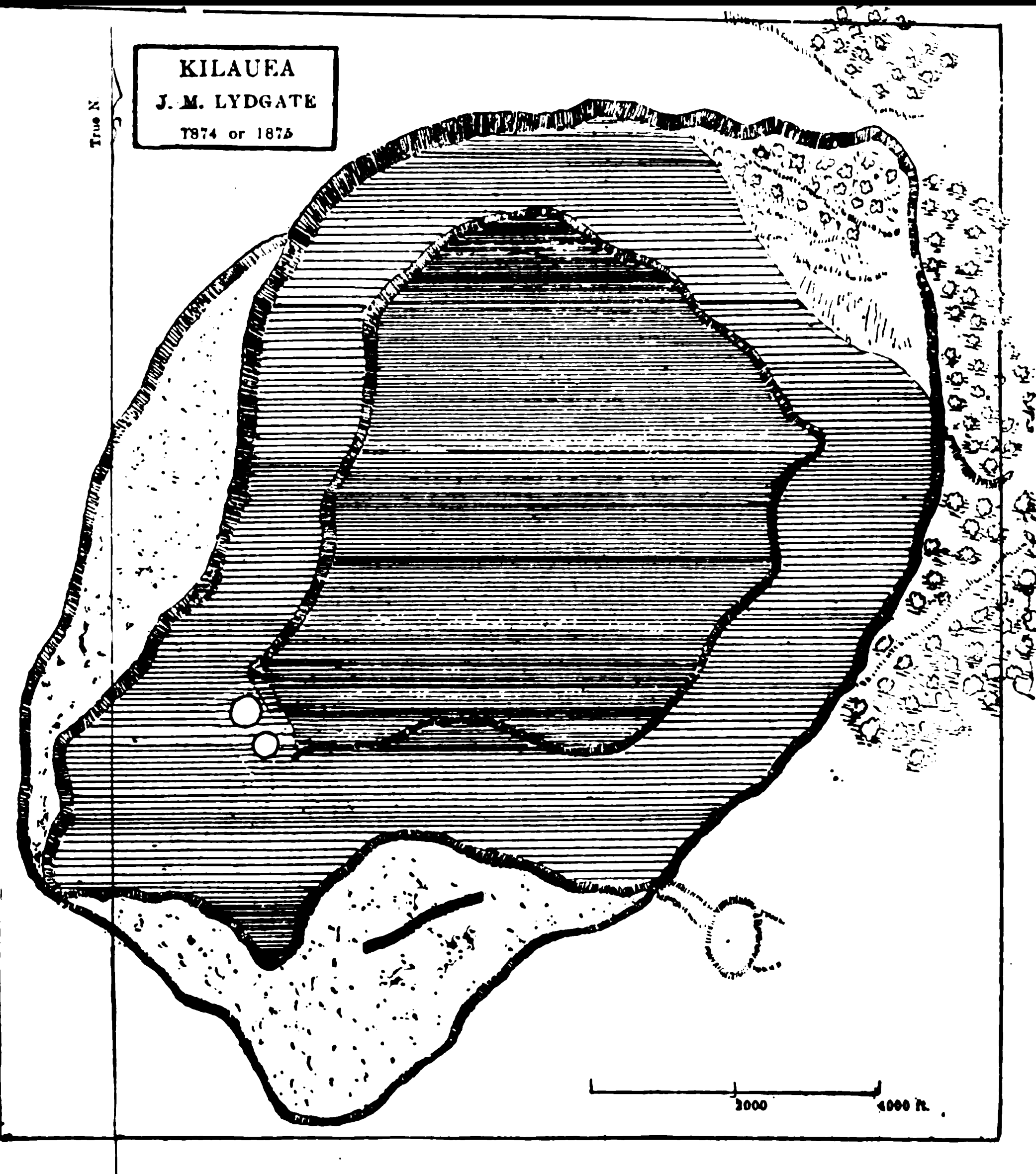

On the volcanoes and volcanic phenomena of the Hawaiian ...

James Dwight Dana, Edward Salisbury Dana

June 26, 1889.

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A. Agassiz

From James D. Dana

[From the American Journal of Science, Vols. XXXIII–XXXVII, 1887–89.]

ON THE VOLCANOES AND VOLCANIC PHENOMENA OF THE HAWAIIAN ISLANDS.

By James D. Dana.

With a Paper on the

PETROGRAPHY OF THE ISLANDS.

By Edward S. Dana.

[FROM THE AMERICAN JOURNAL OF SCIENCE, VOL. XXXIII, JUNE, 1887.]

ART. XLIV.—*History of the Changes in the Mt. Loa Craters, on Hawaii;* by JAMES D. DANA. With Plate XII.

THE instructive papers of Messrs. Emerson, Van Slyke and Dodge (p. 87) are a good beginning for a future history of the Hawaiian volcanoes. The earlier history, for sixty-five years back, has a source of material in three scientific reports: that of Captain C. E. Dutton (1883),* the memoir of Mr. Wm. T. Brigham, who visited the region in 1864 and 1865,† and the report of the writer,‡ after an examination in 1840, each of which may be assumed to give the facts as they were observed, whatever the value of the explanations offered. In connection with these should be mentioned the descriptions and illustrations in the Narrative of the Exploring Expedition by Captain Wilkes.§ There are also accounts from various other sources which, although in many cases overdrawn, contain information of

* In the Fourth Annual Report of the Director of the U. S. Geol. Survey, 1882–'83, 140 pp. roy. 8vo, with maps and plates of Kilauea, the Mt. Loa crater, etc.

† Notes on the volcanoes of the Hawaiian Islands, with a history of their various eruptions, by Wm. T. Brigham, A.M., Mem. Boston Soc. Nat. Hist., vol. i, Part ii. 126 pp. 4to, with four plates (including a new map of Kilauea) and several woodcuts. 1868. Mr. Brigham's map is reproduced in Captain Dutton's Report, but without explanation or remark.

‡ Report Geol. Wilkes Expl. Exped., 756 pp., 4to, with folio atlas, 1849.

§ Narrative of the Expl. Exped., by Charles Wilkes, U. S. N., Commander of the Expedition, 1838–1842. 5 vols. roy. 8vo, with an atlas. 1845. The account of the volcanoes of Hawaii is in vol. iv. Captain Wilkes required his officers to keep journals, and used them as a source for part of the material for his Narrative.

much importance. In my Geological Report I endeavored to bring the history in a brief way down to 1849, the time of its publication. Mr. Brigham reviewed the same to the date of his last examination in 1865.

Captain Dutton gives his own observations in 1882, and his conclusions, with a few citations from other accounts; but the condition of the crater at the time of the visit was not favorable for an appreciation of the phases of the volcano or for an understanding of all its phenomena; and he is led to doubt much that was well reported before him, very much more than appears, in the light of the facts presented beyond, to be reasonable.

The conclusions he gathers from the accounts, as stated on pp. 117, 118 of his Report, are the following:

"At the present time [1882] the liquid lava columns stand about 435 feet higher than they did forty years ago. No record has ever been kept of the progressive action by which these changes have been brought about. Nothing remains to show the successive steps in the accretion of lavas which gradually filled up the interior pit. The only guides we have are the fragmentary accounts of numberless visitors describing the condition of Kilauea from time to time. These are all so incoherent, and so grossly wanting in precision, that it is impossible to frame a connected account of the process.

"There are, however, a few general features of the process which appear, and these may be briefly summarized. All accounts go to show that the height of the liquid column oscillates in an irregular manner; and while most of these oscillations are small, usually not exceeding ten to fifteen feet, yet in exceptional cases they are very much greater. Whenever the liquid column rises there is a tendency to overflow the margin of the pool which surrounds it, and this frequently happens. The quantities of lava thus outflowing and spreading out over a considerable area vary extremely, being sufficient sometimes to cover no more than a few acres to the thickness of a very few feet, while on rare occasions a square mile or two may be overflowed with a considerable body. The duration of these overflows is also extremely variable. Sometimes it is a single belch or surge lasting but a few minutes. It is quite common for the lava to run in this way for a whole day, and in large outflows it may run for two or three weeks without interruption. Sooner or later the liquid column sinks and the overflow ceases. The eruptions are not by any means confined to the lakes, but break out at unexpected places. One of the most favored spots for this action is the former focus of the Old South Lake, which for several years has been completely frozen over. The cooling lava invariably takes the form of pahoehoe."

The above meagre summary, which Captain Dutton's facts, and his knowledge of the descriptions of earlier "visitors,"

have enabled him to present, contains little, it is true, that is important to the science of volcanoes. After a careful sifting of all the earlier accounts with reference to statements bearing on the progressive changes in the craters of Kilauea and Mt. Loa, I have found that very much more is taught. What, and of what significance, the following pages aim to show.

I. KILAUEA.

Besides the publications already mentioned, the following, relating to Kilauea prior to 1841, are cited from beyond, and referred to by means of the Roman numerals here prefixed. I add some descriptive and critical notes that the facts reported may be received with proper discrimination.

I. *a*. Journal of a Tour around Hawaii [in August, 1823] by a Deputation from the Mission of the Sandwich Islands. 264 pp. 8vo, with six plates. Boston, 1825 (Crocker & Brewster). "Drawn up by the Rev. Wm. Ellis," of England, one of the party, "from minutes kept by himself and by his associates on the tour, who subsequently gave it their approbation." Contains, facing p. 136, a night-view of "the south end of Kilauea," from a sketch taken by Mr. Ellis, looking southwestward,* engraved by S. S. Jocelyn, of New Haven, Ct. See also Missionary Herald, xxii, 25, 1826. *b*. London edition, "with large additions," 1826, under the title, "Narrative of a Tour through Hawaii;" 3d edit., March, 1827, 480 pp. 8vo. Contains, facing p. 226, a day-view of the "southwest end" of Kilauea, engraved, from the same sketch, in England; but a large cone stands where was the foot of a lava-stream descending the west wall; two cones are omitted; the active cones give out steam quietly. See p. 438.

II. Polynesian Researches, by Rev. Wm. Ellis, 2d edition, 4 vols. 12mo, London, 1831. The first edition, 2 vols. 8vo, published in 1829, contains nothing about Hawaii. In preparing for a second edition, the Narrative (I *b*) was added (as the fourth vol.); and, for a frontispiece to this volume, a new engraving of Kilauea (from a painting—a night-view) was introduced, having the subscript, "The volcano of Kilauea in Hawaii. Sketched by W. Ellis. Painted by E. Howard, Jr. . . . London, 1831." A copy of this plate, with the subscript, "Blowing Cones. Reproduced from Ellis' Polynesian Research, 1823," is contained in the Report of Captain Dutton. An outline copy is introduced beyond, on p. 441. The plate differs widely from those of 1825 and 1826;

* Leaving the north end of the crater, says the "Journal," p. 145 (and "Narrative," p. 247) "we passed along to the east side, where Mr. Ellis took a sketch of the southwest end of the crater." And then, in the next sentence, "As we travelled from this spot we unexpectedly came to another crater" nearly half as large as the former. The native name of it is Kirauea-iti [Kilauea-Iki, as now written]; "it is separated from the large crater by an isthmus nearly 100 yards wide." The position from which the view was taken was hence north of Byron's hut (p. 440), either on the isthmus referred to or farther north on the bluff adjacent.

and since the text (Polyn. Res., vol. iv, p. 266) gives the same statement as the Narrative as to where the sketch was taken, the artist's fancy is evidently the chief source of the differences. The cones are fewer, but they are as active; and one, placed out in the front, is a grand high shooter, far outdoing any of those on the other plates. Further, the features of the black ledge and the wall above are changed on both sides of the pit, and the Great South Lake is put in a *southeast* recess instead of to the southwest. Mr. Ellis was a second time at Kilauea, but this was before 1826. He then found the crater much more quiet, and "the fires in the south and west burning but feebly."

III. Journal of a voyage to the Pacific Ocean and residence at the Sandwich Islands, 1822–1825; by Rev. C. S. STEWART. 8vo. New York, 1828. Contains an account of a visit to Kilauea, made on July 2, 1825. Am. J. Sci., xi, 363, 1826.

IV. Visit to the South Seas, by C. S. STEWART. 2 vols. 12mo. New York, 1831. In vol. ii, an account of Kilauea after a visit Oct. 9, 1829, not overdrawn like that in the preceding work. Am. J. Sci., xx, 229, 1831.

V. Voyage of H. M. S. Blonde to the Sandwich Islands in the years 1824, 1825, by Right Hon. Lord BYRON, Commander. 260 pp. 4to, with plates. London, 1826. Contains an account of a visit to Kilauea on June 28, 29 (29, 30, American time), illustrated by a folded plate presenting a view of the volcano, by R. DAMPIER, in which the many cones give out vapors quietly, and a map of the crater by Lieut. MALDEN, R. N. (see p. 441 beyond).

VI. Letters of Rev. JOSEPH GOODRICH: *a*, Am. J. Sci., xi, 2, 1826, letter of April 20, 1825; *b*, ibid., xvi, 345, 1829, letter of Oct. 25, 1828; *c*, ibid., xvi, 346, letter of June 12, 1828; *d*, ibid., xxv, 199, 1834, letter of Nov. 17, 1832.

VII. Letter of Rev. A. BISHOP, Missionary Herald, xxiii, 53, 1827, after a visit to Kilauea, Jan. 3, 1826.

VIII. Note of Rev. L. CHAMBERLAIN, after a visit to Kilauea with J. Goodrich, Dec., 1824, Missionary Herald, xxii, 42, 1826; also in Ellis's Pol. Res., iv. 253, and Phil. Mag., Sept., 1826.

IX. *a.* Memoir of DAVID DOUGLAS, by Dr. W. J. Hooker, with portrait, letters and Journal, Companion of the Bot. Mag., ii, 79–182, 1836; the part on Hawaii, pp. 158–177. The visit to Kilauea was on Jan. 23–25, 1834, and to top of Mauna Loa, on Jan. 29; the account of the latter in his Journal, p. 175, and that in a letter to Dr. Hooker, p. 158.—*b.* Letter to Capt. Sabine, dated Oahu, May 3, 1834, partly from his Journal, but with additional material on his barometric, hygrometric, thermometric and hypsometric observations, Journal Royal Geogr. Soc., iv, 333–334, 1834. —*c.* Extracts from the Journal of Mr. Douglas, Mag. Zool. and Bot., i, 582, 1837, and including the letter to Dr. Hooker which describes Mt. Loa.

Mr. Douglas spent a dozen years in travels over N. America (Oregon, California, Hudson's Bay region, etc.) as an exploring

naturalist, and twice visited the Sandwich Islands, making collections and observations in botany, zoology, etc., part of the time under the auspices of the Horticultural Society of London. His instruments included a barometer, chronometers, a reflecting circle, large dipping needle, etc. While on an excursion over Hawaii in July, 1834 (then 35 years old), he fell into a pit made to entrap wild cattle and was gored to death.

X. Account, by E. G. KELLEY, of observations made at Kilauea by Captains CHASE and PARKER, on the 8th of May, 1838, and published, after submission to Capts. C. and P., in this Journal, xl, 117, 1841, with a map of the crater (see p. 448).

XI. Notes of Count Strzlecki, after a visit to Kilauea in 1838, in his "New South Wales and Van Diemens Land," 8vo, London, 1845, and cited in quotation marks from, he says, his "manuscript notes." Also a note in the Hawaiian Spectator, i, 436, but the facts differently stated—see note, p. 449.

XII. Account, by Captain JOHN SHEPHERD, R. N., after a visit, Sept. 16, 1839, contained in the London Athenæum of Nov. 14, 1840, p. 909.

XIII. Account, by Rev. TITUS COAN, dated September, 1840, Missionary Herald, xxxvii, 283.

XIV. Rev. H. Bingham's Residence of thirty-one years in the Sandwich Islands, 1847.

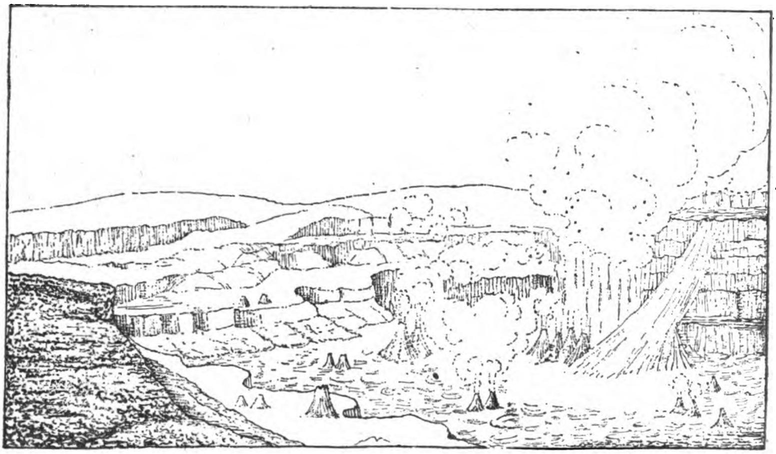
1. KILAUEA FROM JAN. 1823 TO JAN. 1841.

For convenient reference in describing the varying phases of the volcano, I introduce (see Plate XII) a view of the crater of Kilauea from its north side, as it appeared in December, 1840,* when it had, as a consequence of the eruption about six months before, a lower pit, and a "black ledge," besides the great southern lake of lavas, Halema'uma'u, all well defined. The artist of the expedition, Mr. J. Drayton, has, with the aid of his camera lucida, brought out well the features of the scene. The more distant wall is about 14,000 feet from the near side, and this is not far from the idea the view conveys, quite as nearly so as it appears to be in the actual scene. But one or two points of geological importance have been overlooked which should be mentioned to forestall wrong inferences; one is, the omission of the stratification of the wall, which is a marked feature; and another is the giving a slight concavity to the floor of the crater in the northern or near part, which was not a fact. The small jets of vapor over the bottom arise, with a single exception, from fissures or cavern-like openings; and such escapes of vapor are greatly multiplied by a rain. The exception was that of a lava-lake, about 200 feet in diameter, named Judd's Lake in the "Narrative," which was the

* Copied from the plate facing page 125, in the 4th volume of Wilkes's Narrative.

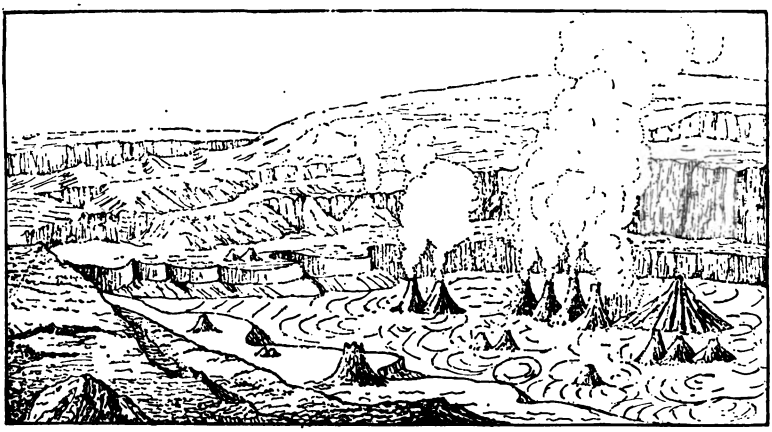
larger of two small lakes that were active in November, at the time of my visit.

1. Before the Eruption of 1823.—The condition of Kilauea prior to the eruption of 1823 is known only from statements in the "Journal of the Deputation of the Mission" (I*a*), or the "Narrative" (I*b*), and in a letter of Rev. Joseph



1. "The south end of Kilauea." Sketched by W. Ellis.

Goodrich (VI*a*), both made after the visit of August 23, and based on evidence, seen by each of the party, that a high-level



2. "The southwest end of Kilauea." W. Ellis, del.

mark existed in a "black ledge," as it was then called, running like a terrace-plain around the interior, some hundreds of feet above the bottom. "It was evident," says the Journal, "that

the crater had been recently filled with lavas up to the black ledge;" and Mr. Goodrich remarks that "the black ledge was made by the crater's being filled to that level" (VI*a*). This conclusion was evidently derived from the features of the ledge; for this was the first visit of foreigners. Still they may have had a hint from the islanders, one of whom in 1826, told the Rev. Mr. Bishop that "after rising a little higher the lava would discharge itself toward the sea as formerly by an underground way." I introduce here (fig. 1) an outline copy of the plate in the Journal (I*a*), and also (fig. 2) of that in the Narrative (I*b*), both reduced. They corroborate one another in all the main points, though having differences due either to corrections in England, or to changes suggested by Mr. Ellis. The black ledge borders the lower pit around, as in 1840, but is very narrow.

The eruption probably took place between the preceding months of March and June. At Ponahohoa in Kapapala, they saw (I*a*, p. 117) a large sunken area, 50 feet deep, fissured in all directions, besides steaming chasms, and ejections of fresh lava, which they were told by the natives of the place were made by Pele two moons before; and by natives of Kearakomo, five moons before (p. 151). It is added: "Perhaps the body of the lava that had filled Kilauea up to the black ledge" "had been drawn off by this subterranean channel."*

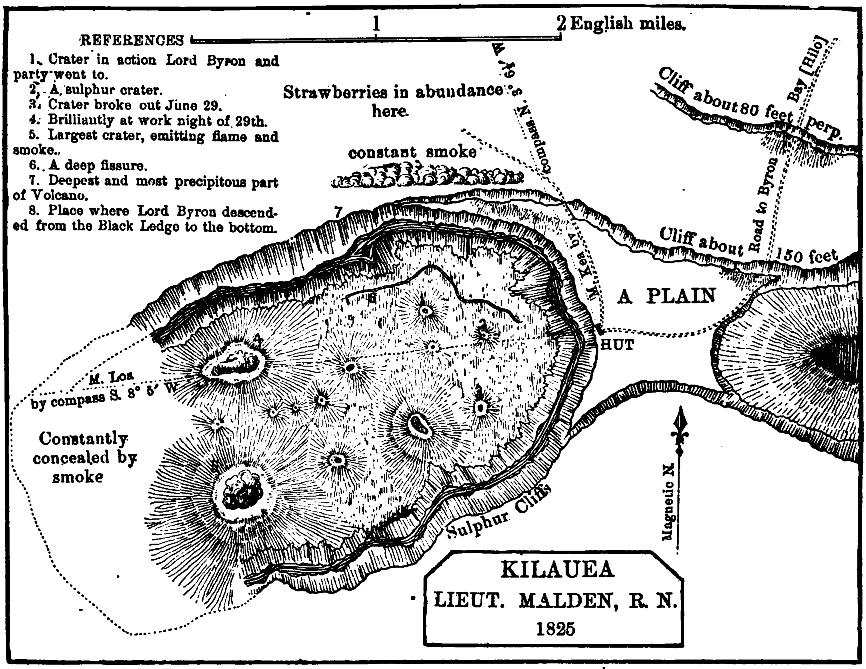
2. After the Eruption of 1823. *a. Size of the Crater.*—The discharge, wherever it took place, was followed in the crater by a down plunge of part of the floor, giving Kilauea its lower pit and "black ledge." The depth of the lower pit was estimated by the Mission party at 300 or 400 feet; and the total depth of the crater, 700 to 800, making the former nearly or quite half the latter. Mr. Goodrich, who was at the crater with the party, and three times afterward before April, 1825, estimated the whole depth at over 1000 feet, and that of the lower pit at 500 (VI*a*), the latter again half the former.

Lieut. Malden, R. N., of the Blonde (V, p. 184) made a map of the crater (of which the following is a copy reduced one-third),† and measured the height of the high northwest wall above the black ledge. He states, in a note to Lord Byron's work, that he obtained by triangulation, 8209 feet for the distance across from the "Hut," the place of encampment, to the

* It is a favoring fact that Mr. David Douglas in January, 1834, had information from the natives that in 1822 there was a great discharge in the Kapapala direction (IX*b*, p. 170). The same region was fissured and had its small ejections of lava at the eruption of Kilauea in 1868, and probably a large outflow off the coast.

† This copy has the lettering of the original, excepting the title, which is "A plan of the Volcano Peli, in the island of Owhyhee, by Lieut. Malden, R.N., 1825;" also the east half of Kilauea Iki is omitted.

highest part of the western wall, a point numbered 7 on his map, which is, in all probability, Kamohoalii of Mr. Dodge's map (Plate II of this volume), and 5° 55′ for the angle subtended by the wall between its summit and the black ledge; and that he thus made the height of the wall, 932 feet. There is here a slip, for the data give 851 in place of 932. The most recent survey makes that distance 8750 feet, using which



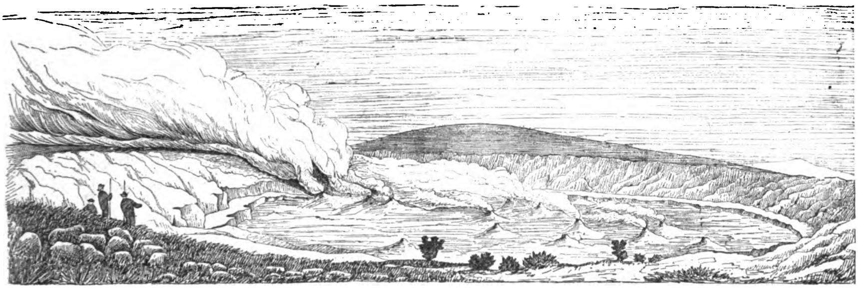
KILAUEA
LIEUT. MALDEN, R. N.
1825

number in the calculation we get 907 for the height of the wall. It is therefore probable that 900 feet is not far from right.

Lieut. Malden *estimated* the depth of the lower pit at 400 feet (and Dampier's sketch beyond accords with this); but he saw it only from above (illness preventing his descent), and more than two years after the eruption. The observers of August, 1823, and Rev. Mr. Stewart in 1825, made it nearly or quite half of the total depth (giving for the total 1700 or 1800), and this is assumed by Mr. Goodrich in his later letters.

All accounts and pictures, together with Lieut. Malden's map, make the black ledge narrow. The plates from Ellis's sketch in the "Journal" and "Narrative" (p. 438) make the eastern side of it the broader; but the part shown is really the south-

eastern, toward the sulphur banks; and there Rev. E. Loomis, in June, 1824, found it by measurement to be "nearly fifteen rods" wide.* Lord Byron, on his descent into the pit, went from the northeast to the northwest side, and says: the width (referring probably to the north side) varies from four or five feet to upwards of twenty. The annexed sketch,

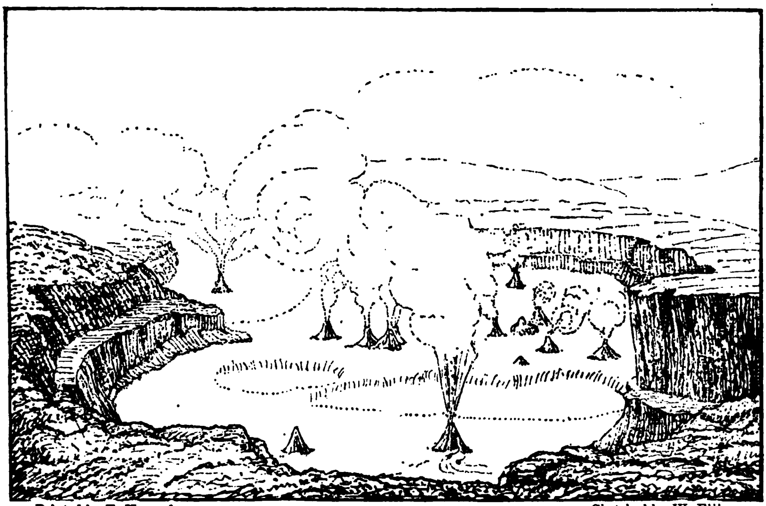


4. Kilauea. Drawn by R. Dampier.

which is a copy (reduced one-third) of the plate by R. Dampier, making the frontispiece to Lord Byron's "Voyage" (V), has the ledge very narrow.† It is not quite certain what part of the crater the view represents. Mts. Loa and Kea are in the

* Memoir of Wm. T. Brigham, p. 407.

† The plate in Ellis's Polynesian Researches makes the breadth about the same on the two sides, as the following outline copy (reduced a sixth) shows; but, as



Painted by E. Howard. Sketched by W. Ellis.

5. The Volcano of Kilauea, in Hawaii.

has been explained (p. 436) it has little value as to details. In the relative depths, however, of the lower pit and upper portion it agrees better with the several descriptions than the other plates.

distance and the chief seat of fires is to the left, and by comparing with Lieut. Malden's map and Drayton's plates the position required for such a view can be ascertained. Rev. C. S. Stewart describes the ledge as in some places many rods, in others a few feet wide. Mr. Goodrich (VI*a*), after having measured the whole length of one side, remarks that "it is like a stair, although it is half a mile wide some part of the way"—which part he does not say.

On the 22d of December, 1824, Mr. Goodrich (VI*a*), with Mr. Chamberlain (VIII), measured the circumference of Kilauea at the top *with a line*, and made it 7½ miles; which is the length it has on Mr. Dodge's map, the scale of which is 500 feet to the inch. They measured the crater also on the black ledge, going half way around it and estimating for the rest, and obtained, as the result, 5½ miles for the circumference of the lower pit, which I find to be probably nearly right.

b. Condition of the crater after the eruption.—The "Journal" (I*a*) says, on page 131, "the southwest and northern parts of the crater were one vast flood of liquid fire, in a state of terrific ebullition." "Fifty-one craters, of varied form and size, rose like so many conical islands, from the surface of the burning lake. Twenty-two constantly emitted columns of gray smoke or pyramids of brilliant flame [lava-jets?], and many of them at the same time vomited from their ignited mouths streams of florid lava which rolled in blazing torrents down their black, indented sides into the boiling mass below." In a night scene, p. 136, "the agitated mass of liquid lava, like a flood of metal, raged with tumultuous whirl," and "at frequent intervals shot up, with loudest detonations, spherical masses of fusing lava or bright ignited stones."*

Descending to the black ledge (Journal, p. 144) they "entered several small craters," "bearing marks of very recent fusion," "and many which from the top had appeared insignificant as mole-hills" proved to be "12 or 20 feet high." They also collected the "hair of Pele," and afterwards found it seven miles south of the crater, "where it had been wafted by the winds."

* The plate in the "Journal" of the "south end" represents "one" continuous area of lavas in "tumultuous whirl," in accord with the text, and that in the "Narrative" is similar, but with more extravagant whirls, for they are hundreds of feet in diameter, and even the black ledge is covered by them. The engraver has apparently tried to conform to the description. In the plate of the Polynesian Researches, the liquid surface is confined to the great South Lake, and a separate large area (or two of them), and nothing of the "tumultuous whirl" is represented, although the expression remains in the text (p. 245). It seems probable from the description that the party saw only "one" great lake, that of the South end, and that great overflowings sent streams far northward. The height of the throw of stones (see plates) is evidently an exaggeration, as it is inconsistent with the condition of "ebullition" at the time, and with all that has been said of Kilauea since. The text says "shot up," but does not say how high.

Mr. Ellis argues from the "conical islands" (*Ib*, p. 226, and II, iv, p. 237) that the boiling caldron of melted lava "was comparatively shallow," implying that the cones stood on the solid bottom of the lake. He also noticed that the walls of Kilauea were "composed of different strata of ancient lava."

On page 144, the Journal (I*a*), after describing long, covered, tunnel-like chambers occupying the emptied interiors of lava streams, the upper surface rippled, the roof "hung with red and brown stalactitic lava," and "the bottom one continued glassy stream," says that they followed one such covered way "to the edge of the precipice that bounds the great crater, and looked over the fearful steep down which the fiery cascade had rushed, the fall "several hundred feet." The plate in the "Journal" (p. 438) represents rudely such a stream descending the *west* wall (like that of 1832, on the opposite side of the crater); but it is strangely (perhaps because badly drawn) omitted from the plate in the "Narrative."

Mr. Goodrich's letter on April, 1825 (VI*a*), does not distinguish the events of his first four visits. He observes that in February, 1825, he counted twelve places where the lava was red hot, and three or four where it was "spouting up lava 30 or 40 feet"; and mentions the escape of vapors in many places, making "a tremendous roaring." On December 22, 1824, a crater opened in the bottom where the lavas boiled like a fountain, with jets 40 to 50 feet high, and flowed off 50 or 60 rods.

Lord Byron's "Voyage" states (p. 184) that on June 30th, 1825, "fifty cones of various height appeared below," at least "one-half of these in activity"; and Mr. R. Dampier's sketch represents such a scene. Lieut. Malden's map makes the cones fewer and very broad, unlike the descriptions; crater No. 5 (p. 440) is probably Halema'uma'u, for the distance from the hut is right for it, and if so the part "concealed by smoke" was of much less extent than was supposed by the party.

Rev. C. S. Stewart, who was with the party from the Blonde, makes the same statement (III) as to the number of "conical craters," and the position of the great seat of action in the southwest. He describes (p. 298) the black ledge as covered with tortuous streams of shining lava bearing "incontestible evidence of once having been the level of the fiery flood," and adds that "a subduction of lava" had "sunk the abyss many hundreds of feet to its present depth." A cone on the bottom, visited by the party, spoken of as "one of the largest," "whose laborious action" had attracted attention during the night (p. 304 and No. 1 on the map), was judged to be 150 feet high "a huge, irregularly shapen, inverted funnel of lava, covered with clefts and orifices, from which bodies of steam escaped with deafen-

ing explosions, while pale flames, ashes, stones and lava were propelled with equal force and noise from its ragged yawning mouth." The following night, crater No. 3 (Malden's map) became suddenly eruptive, and a lake of fire (No. 4?), perhaps two miles in circumference, opened in the more distant part.

Mr. Bishop, after a visit, Jan. 3, 1826, reported (VII) a similar condition of the crater; and also the filling up of the lower pit since August, 1823, of 400 feet—probably on the view that the original depth was 900 feet.

It will be observed that the above citations from Mr. Ellis and other early writers on Kilauea contain no mention of "blowing cones," except what is implied in the general descriptions. This is true of other later reports, including that of Captain Wilkes, who saw no cone in action. Further, it appears that the blowing described was done partly by the small cones, and partly by openings or oven-shaped places over the floor of the crater, as implied in the statement of Mr. Goodrich (p. 443), just as was true in 1886. They blow violently because they are small, or have relatively small apertures, so that the imprisoned vapors, on bursting the envelope of liquid or semi-liquid lava, go out with a rush and a roar. The only heights of ejections of lava mentioned are 30 to 40 and 50 feet; and the heights of cones 12, 20, and, for "one of the largest cones," 150 feet; which are common facts of later time down to the present.*

The close correspondence between the heights and character of ejections given in the earlier accounts, and those of recent years, is interesting as proving long-continued uniformity as to kind and quality of work even to the blowholes. The activity was however greater and more general than has been witnessed for many years. There are exaggerations, but they are mostly confined to the pictures, and to some of the general descriptions. The *estimates* made were usually below the truth, from honest caution.

Further, Mr. Ellis guards the reader, as has been shown, against the inference, from the island-like position of the cones in the region of liquid lavas, that they were floating-cones.†

* It is obvious that the high-shooting cone in the plate of Ellis's Polynesian Researches (II), blowing to a height of 700 or 800 feet (measuring it by the height of the upper wall), is the artist's fancy sketch, as suggested on page 436. It is wholly un-Kilauean and fundamentally out of place. The earlier plate from Mr. Ellis's sketch in the 'Journal' (I), also exaggerates, but only a third as much except over the South Lake.

† On page 111 of Captain Dutton's Report, the author presents the case differently, as follows.—"The earlier visitors to Kilauea whose accounts of it are now accessible speak of a phenomenon which did not exist at the time of my visit. I refer here to what has been termed 'blowing cones' within the lake. Ellis, in his account of Kilauea in 1823, described them as 'conical inverted funnels' rising to heights varying from twenty to forty, or even fifty feet above the surface

c. Progress in the filling of the lower pit.—As early as February, 1825, Mr. Goodrich stated, in view of the overflows he had observed, and the making of a "mound" over 60 feet high in six weeks, that the pit had begun to fill up (VI*a*); and in his letter of October 25, 1828, (VI*b*) he made the pit to have diminished in depth since August, 1823, by 300 or 400 feet. A year later, Oct. 25, 1829, Mr. Stewart (VI) described the lavas as still 200 feet below the level of the black ledge—which implies a filling of 400 feet, if the depth in 1823 was 600 feet, and of 600 if 800 feet deep. He states that although the crater was comparatively quiet, the bottom was crossed by a chain of lava-lakes, one of them a mile wide, throwing up masses of lava 15 to 20 feet; and that there were also six cones in action in the lower pit and one on the black ledge. Here again the height of the ejections mentioned is small. In October, 1830, the black ledge was still distinct (XIV, p. 387.)

3. Before the eruption of 1832.—Before the eruption of 1832, as Mr. Goodrich states, after a visit to Kilauea "about the 1st of September" of that year (VI*d*), "the crater had been filled up to the black ledge and about fifty feet above, about 900 feet in the whole since I first visited it, and it had now again sunk down to nearly the same depth as at first (in 1823), leaving as usual a boiling caldron at the south end." The precise time of the discharge and down-plunge is not stated. He adds, "The earthquake of January last had rent in twain the walls of the crater on the east side, from the top to the bottom, producing seams from a few inches to several yards in width, from which the region around was deluged with lava." "The chasms passed within a few yards of where Mr. Stewart, Lord Byron, myself and others had slept," "so that the very spot where I have lain quietly many times is entirely overrun with lava." (See map, p. 440). This outflow is stated by Mr. David Douglas (IX*b*) to have occurred in June, 1832. We may conclude, therefore, that the time of eruption was probably in January, but perhaps in June of 1832; certainly before September 1832, the time of Mr. Goodrich's visit.

4. After the eruption.—*a. Size of the crater after the eruption.*—As to the new depth of the lower pit, we have first Mr.

of the lake, with openings at the top from which jets of vapor and sometimes spouts of lava were thrown out. As many as fifty were seen at one time within the great lava lake then existing, and most of them were simultaneously active. The same phenomenon was described in 1825 by parties from H. B. M. frigate Blonde. They were also observed by Wilkes in 1841, and have frequently been seen within the last ten or fifteen years by many other visitors. They appear to have been composed of solidified but very hot lava. None of them were permanent, but after a short period of activity they were either melted down, or shifted their positions. Ultimately, no doubt, they were remelted. That they shifted their positions is fully attested by many observers. Most probably they were masses of solidified lava floating like bergs in the lake."

Goodrich's statement above cited, "the same depth as at first," and the additional remark that the filling amounted to "about 900 feet"; which statement would make the depth of the lower pit after the eruption of 1832 nearly 900 feet, and of the crater from top to bottom 1750 feet. This estimate of the original depth accords with his view in 1825 that the upper and lower walls were of nearly equal height, and that Lieut. Malden's measurement was therefore good for both. There is no published account furnishing data for correcting this estimate.

By letter from Mr. W. D. Alexander, Surveyor General of the Hawaiian Islands, dated March 2, 1887, I learn that his father, Rev. Wm. C. Alexander (who arrived at the Sandwich Islands in 1832) visited the crater on the 12th of January, 1833, four months after Mr. Goodrich's visit, and in his private diary gives the depth of the crater as 2000 feet. This tends to confirm Mr. Goodrich's numbers, although only a rough estimate. He says nothing of any black ledge, except of that at the bottom of the 2,000 feet; and this leads to the inference that the ledge was quite narrow, as in 1823.

On the 22nd of January, 1834, Mr. David Douglas, of Scotland (XI), made careful barometric measurements of the crater, (all the details of which, with the calculation, are given in his letter to Captain Sabine, IX*b*). He obtained for the depth to the black ledge, on the highest northwest side, 715 feet; and to the bottom of the lower pit, 1,077 feet, (mean of two calculations). This makes the depth of the lower pit at that date 362 feet; in addition to which he says that there were 43 feet more to the surface of the liquid lavas.

We thus know that the down-plunge was a fact; and using as evidence only the measurements of Mr. Douglas, and noting that they were made at least a year and a half after the eruption, it was larger both as to depth and breadth than that of 1840. Hence the eruption of 1832—instead of being "a very small one, only remarkable from the fact that the fissure from which it emanated opens at a level of more than 400 feet above the present lava-lakes" with, "so far as known," "no sympathy" "within the lavas of Kilauea"*—was one of Kilauea's greatest, although not registered, so far as known, in any outside stream of lava.

b. Condition after the eruption.—Mr. Goodrich describes the Great Lake at the south end as "60 or 80 rods long, and 20 or 30 rods wide," about 20 feet below the brim; "the whole mass of liquid and semi-fluid lava was boiling, foaming and dashing its fiery bellows against the rocky shore; the mass was in motion, running from north to south, at the rate of two or

* Report of Captain Dutton, p. 124, referring to the eruption near Lord Byron's Hut.

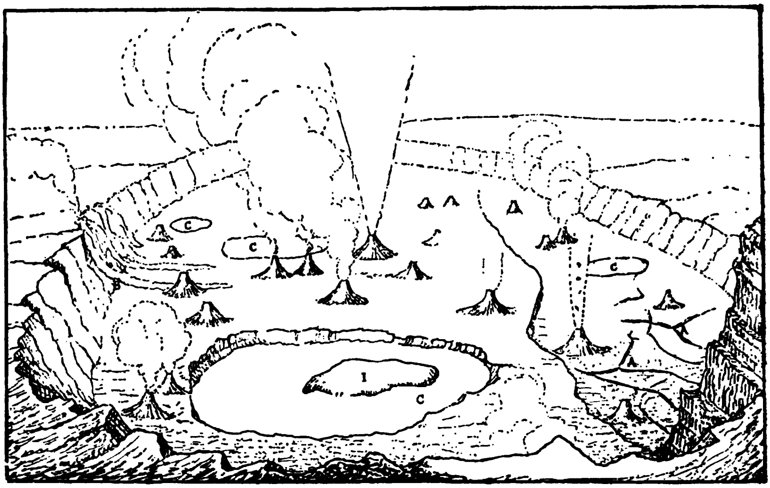
three miles an hour, boiling up as a spring at one end and running to the other." Mr. Alexander, while in the crater four months later, found this lake, "the principal furnace, not in lively action," and ascended, much disappointed; but by the time he had reached the summit, "the grand crater commenced furious action, spouting with a roaring sound, streams of melted lava far into the air." The next day he went again to the bottom, and direct to the great boiling caldron two and a half miles distant," and found it "3000 feet long and 1000 feet wide, tossing its fiery surges 40 or 50 feet into the air." He went to the brink of the lake, but left it on account of the fumes, and three minutes afterward the spot was covered with the lavas of an overflow, "which," he says, "seemed to pursue us as we hastened away." It is important to observe that uniformly the "far into the air" and similar expressions in the general descriptions of travelers become, when put in figures, not far from 30, 40 or 50 feet of actual height.

Mr. Douglas, whose visit was in 1834, reports (XI) that he found two great boiling lakes in the crater, a northern 319 yards in diameter, and a southern 1190 by 700 yards in area, heart-shaped in form. The great southern lake was "at times calm and level, the numerous fiery-red streaks on its surface alone attesting its state of ebullition, when again the red hot lavas would dart upwards and boil with terrific grandeur, spouting to a height which from the distance at which I stood (on the west wall) I calculated to be from 20 to 70 feet. Close by stood a chimney above 40 feet high which occasionally discharged its steam as if all the steam engines in the world were concentrated in it." There were other chimneys over the bottom, some active and others comparatively quiet. In each of the large lakes the lavas had an apparent movement southward, the velocity of which Mr. Douglas measured (by throwing on a block of lava and seeing how long it took to go 100 yards) making it nearly 3½ miles an hour.*

c. *Filling of the pit after the eruption of* 1832.—On the 8th of

* Mr. Douglas's testimony with regard to the Hawaiian volcanoes has been doubted because of his incredible account of what he saw at the summit crater in a letter to the eminent botanist, Dr. Hooker. But I find that injustice has been done him. His *Journal* of his visit to the summit (IX*a*), evidently written by him at the time of his observations, represents the crater as having been long quiet. While at Honolulu, over three months later (May 3), he wrote Capt. Sabine on his various physical investigations and barometric measurements, and gave him the same facts as to the summit crater that he has in his Journal, and partly in the same words. Only three days later (May 6) he wrote his letter to Dr. Hooker—a reasonable letter in all parts excepting its description of the terrific activity and immense size of the Mt. Loa crater. His words indicate a mixing up and magnifying of what he had seen at the Kilauea and summit craters, which can be explained only on the ground of temporary hallucination. Mr. Douglas was an excellent Scotchman, and all the rest of his writings are beyond questioning.

May, 1838, about six years after the eruption, Captains Chase and Parker were at Kilauea. An account of what they saw was written by Mr. E. G. Kelley from their statements, submitted to them for approval, and afterward published in this Journal (X), with a plate from their sketches, but redrawn unfortunately by a New Haven artist who evidently had Vesuvius in his thoughts. An outline copy is here introduced. It was taken at the south end looking northeastward, and has the Great South Lake in the foreground. There is no black ledge on the



Kilauea, from the south end.

west or north side; and to the left instead of a black ledge there is a depressed plain, 40 feet below the general level; the part of it AA was flooded by lavas after having been passed over by the party. The crater was unusually active; there were 26 volcanic cones, 20 to 60 feet high, eight of them throwing out cinders, red hot lava and steam, and six lakes of lava (*c*), including the Great Lake "occupying more space than all the rest."

Not far from the center of the Great Lake there was an island, I, of black solid lava which "heaved up and down in the liquid mass" and "rocked like a ship on a stormy sea." This is the first mention of a "floating island." The descending streams at B are described as streams of sulphur, but as this is not possible they were probably lava-streams in part colored yellow.

The same year, in August or September, Count Strzelecki (who later visited New South Wales), was at the crater (XI). He made some barometric measurements over the region, and

determined the height of the north-northeast wall down to the "boiling surface of igneous matter" to be 600 feet, and makes no mention of a black ledge. He describes six craters with boiling lavas, four of which were only 3 or 4 feet high, a fifth, 40 feet, the sixth 150; the first five as containing 12,000 square feet each, while the sixth—which he says is called "Hau-mau-mau"—contained nearly a million. He alludes plainly to the ebullition over this great lake in the expression "ceaseless impetuosity and fury." He states that the lava sank and rose in all the lakes simultaneously; which is not always true.*

On the 16th of September, 1839, Captain John Shepherd, R. N., visited Kilauea (XII). He speaks of the black ledge as "obliterated;" of cones 20 to 30 feet high, whence issued vapors and lava with loud detonations; of a lake of lava toward the *east* side one mile long and half a mile wide within a cone 100 feet high, from the summit of which he saw the expanse of liquid lava in violent ebullition. He also mentions that the lavas had an apparent flow from south to north, and adds, "caused by the escape of elastic fluids, throwing up the spray in many parts 30 to 40 feet."

5. Before the eruption of 1840.—Mr. Coan states (XIII) "on the testimony of many natives" that in the latter part of May, for a week previous to the eruption, the interior of Kilauea was "one great sea of liquid lavas;" which signifies the existence of many active cones and boiling lakes over the bottom and extensive outflows from the lakes and from opened fissures. He remarks, further, that the ground about Kilauea so trembled from the action below that the islanders avoided the path along the verge of the crater.

There was indubitable evidence at the time of my visit, in November, five months after the eruption, of a recent flooding of the black ledge with lavas, in the tortuous scoria-covered streams of cooled lava that covered it.

6. The eruption of 1840.—No intelligent observer was present at the eruption. Mr. Coan, then a resident of Hilo, returned home from Oahu in July, and his first account of it appeared in September of that year. He found that, through

* Count Strzelecki's note in the Hawaian Spectator occurs in the number for October, 1838, which number also states that he was visiting various portions of the Pacific in H. B. M. S. Fly. It differs widely from the report in his own work, in making the area of the largest lake 300,000 square yards, and those of the smaller "about 5,700 square yards each." His volume is the later publication, and should set aside the newspaper note. Count Strzelecki, in this volume, describes the terraces around the Kilauea crater as vast platforms; makes the height above the sea-level of the north-northeast side of Kilauea two paces from the edge of the precipice, 4,109 feet and 600 feet above the fires below; and observes that this is 950 below the brim of the *ancient* crater, the highest point of which he made 5,054 feet, and its circuit 24 miles. He thought he saw evidence that this greater crater was formerly brimfull of molten lava.

the discharge of lavas and a consequent down-plunge in the crater, there was again a lower pit with a black ledge. He gathered facts showing that the eruption began on the 30th of May, made itself apparent at intervals down the eastern slopes of the mountain, finally broke out as a stream twelve miles from the coast and flowed into the sea just south of Nanawale; and that the flowing continued for three weeks. The condition of the crater in November, the time of my visit, agrees well with the view in the accompanying Plate (Pl. XII) which was taken two months later. The route to the seashore was surveyed by the officers of the Expedition in January, and less perfectly by myself in November.

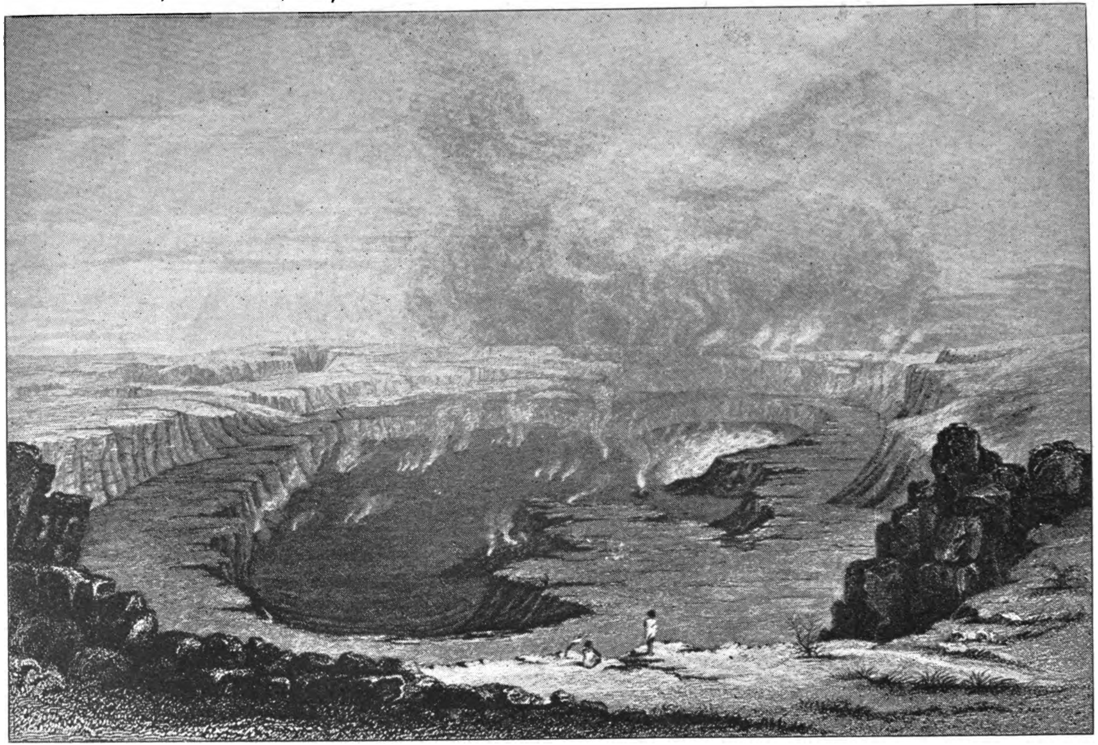
My failure to survey the whole route of the lavas to the seacoast and investigate other parts of Hawaii was in obedience to orders. The vessel of the Expedition to which I was attached—the sloop-of-war "Peacock"—was at the time already under sailing orders for hydrographic work in the equatorial regions of the Pacific; and, although the geologist of the Expedition, I was required to go off with her, away from the most important field of geological investigation in the ocean. Only a week was allowed me for Hawaii. I left the region of volcanoes with a silent protest—the only safe kind—but found compensation through work in another field; and though an old field to me, it was one of unexhausted delight and instruction—the coral islands of the central Pacific. I was enabled to add much to the knowledge of reefs, corals and crustaceans which I had gathered during the preceding season in the Paumotu, Society, Samoan, Friendly and Fejee Islands, by excursions and studies in the Union Group of atolls, the Phœnix Group, the Kingsmill or Gilbert islands, and others. Captain Wilkes had once (while we were off Patagonia) sent me word, when I was seeking information from the log-book of his vessel as to the winds of a Cape Horn gale, that he had that department in charge. At the Hawaiian Islands it was made to appear that at his pleasure, he had the geological department also in charge, although he knew nothing of the subject. The "Narrative," however, was intended to include all departments; and the energetic commander was never conscious of incapacity in any direction.

7. After the eruption of 1840.—*Size of the Crater.*—Capt. Wilkes states, on page 123 of the 4th volume of the Narrative, that the "black ledge surrounds it [the crater] at the depth of 660 feet, and thence to the bottom is 384 feet;" and four pages beyond: "the black ledge is of various widths, from 600 to 2,000 feet." The black ledge "was found [to be] 660 feet below the rim." The floor of the crater "was afterwards found to be 384 feet below the black ledge, making the whole depth 987 [1,044?] feet below the northern rim."

The observations here reported were made in December, 1840, the party leaving on the 18th for the top of Mt. Loa. Other observations on Kilauea were made by Capt. Wilkes and his officers just a month later, in January; and these include a topographic survey of the crater by Capt. Wilkes, who says: "I measured my base and visited all the stations around the crater in their turn." On page 175 it is stated that the observations of one of the officers of the expedition, Lieut. Budd, made the depth to the black ledge 650 feet, and thence to the bottom 342 feet, whence "the total depth 992 feet." On page 179, we learn that Lieut. Eld was instructed to make the measurement of the depth, "as I was desirous of proving *my own* as well as Lieut. Budd's observations;" and then follows the remark, "The measurements coincided within a few feet of each other." Had the precise numbers obtained by Lieut. Eld been reported we might be able to remove the doubts left by the varying statements. But the fact that Lieut. Budd's results are inserted by Capt. Wilkes on his own map of the crater is a strong reason for believing that the coincidence was between the results obtained by the two Lieutenants.

I add here a few words from my own report, on the surface about Kilauea, on the stratification and rock of the walls and the absence from them of scoria, and on the escaping vapors of the Great Lake. "The country around [Kilauea] is slightly raised above the general level, as if by former eruptions over the surface." The walls "consist of naked rock in successive layers" "and look in the distance like cliffs of stratified limestone." The rock is a heavy compact dark gray to grayish black lava [basalt] containing usually fine grains of chrysolite; and no layers of scoria like that making a crust of two to four inches over the solidified lavas from the lava-lakes, intervene even in the walls of the lower pit, each new stream having apparently melted the scoria-crust of the layer it flowed over. While the cooled lava-streams over the bottom were of the smooth-surfaced kind [and would be called pahoehoe] there was the important distinction into streams having the scoria-crust just mentioned, and those having a solid exterior and no separable crust, pointing to some marked difference in conditions of origin. "The vapors rising from the surface of the Great Lake were quite invisible until reaching an elevation where part became condensed by heat" (p. 179); here began "a column of wreaths and curling heaps" and upon this column "the broad canopy of clouds above the pit seemed to rest" (p. 172).

[To be continued.]



CRATER OF KILAUEA. J. Drayton, U. S. Expl. Exped., 1840.

[From the American Journal of Science, Vol. XXXIV, August, 1887.]

Art XI.—*History of the Changes in the Mt. Loa Craters;* by James D. Dana. Part I, Kilauea.

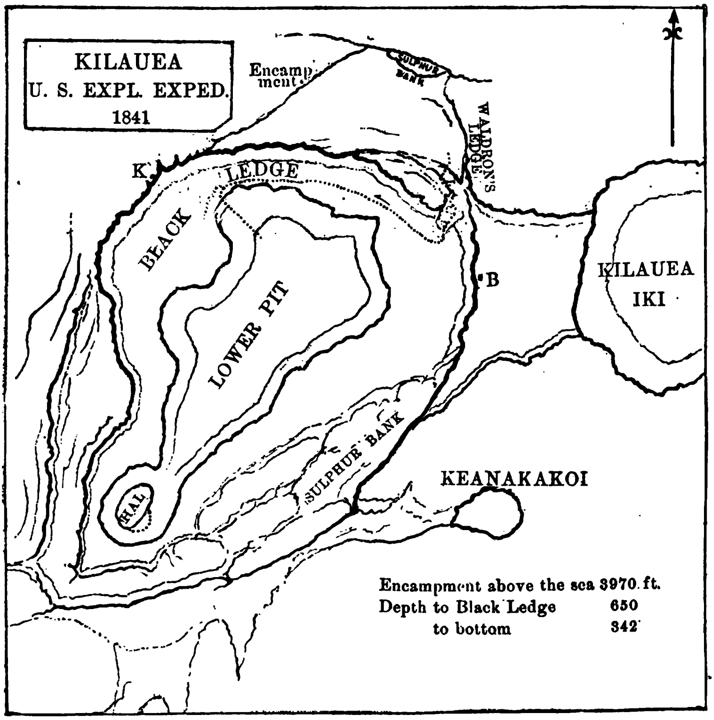
[Continued from page 451, vol. xxxiii.]

2. Kilauea from January 1840 to 1868 inclusive.

The history of Kilauea thus far presented sustains the statement of my Expedition Report that three great eruptions occurred in the seventeen and a half years between the early part of 1823 and the summer of 1840, with intervals between of eight to nine years. The history reviewed also indicates that the method of change was, in a general way, alike for each interval, from the emptied state of the pit to that of high-flood level preparatory to discharge; and alike in the down-plunge of the floor consequent on the discharge. Further, the various accounts agree in referring the filling of the pit to outflows of lavas from lava-lakes, cones and fissures over the bottom of the crater, and in mentioning no facts that point to other concurring means.

During the following twenty-eight-year period, from 1840 to 1868, these several subjects received not only contributions of new facts, but the most fundamental of them, on the method of filling the pit, facts enough for a widened and apparently final explanation. Even within the first six years of the twenty-eight the demonstration was made out, though not published until 1851. The only down-plunge of the floor in this period, producing a lower pit, occurred at its close in 1868.

As the emptied state of the crater is the starting point for this second period of the history, and future changes have a degree of dependence upon it beyond what is generally understood, Wilkes's map is presented here in outline. It is reduced one-third lineally, and is so labelled as to bear its own explanations. The only additions are B, for Lord Byron's encampment, and K, for Kamohoalii, the highest point on the western wall. The scale of the reduced map is 5000 feet to the inch. The base of the upper and lower walls is indicated on it by a fine line. The position of this line in the lower pit shows a



wide divergence from Mr. Drayton's sketch (Pl. XII). My observations put the truth between the two; the walls were largely vertical, but had for long distances a high talus of lava blocks, to which additions were being made by frequent falls even eight months after the eruption. Only at one place was the descent from the black ledge to the bottom gradual, and this was on the northwestern side, where was a convenient way down.*

* See my Exped. Geol. Rep., p. 176. Captain Wilkes's map differs from Mr. Drayton's sketch also in the small width at the neck between the lower pit and Halèma'uma'u. My impressions accord with the sketch, but are of no weight

(1.) *Changes in the Crater from* 1841 *to* 1849.—The changes after the year 1840 went forward in the usual quiet way, varying much from time to time, but on the whole with some increase in activity. In July, 1844, "the Rev. Mr. Coan was near when the large lake overflowed its margin on every side, spreading out into a vast sea of fire, filling the whole southern part of the crater as far as the black ledge on either side, and obliterating the outlines of the cauldron;"* and this was an example of what was often happening; but sometimes more extensively. Only two years afterward, in June of 1846, Mr. Coan reports† that "the repeated overflowings had elevated the central parts of the crater 400 or 500 feet since 1840, so that some points are now more elevated than the black ledge." This last statement implies that *in only six years, the lower pit, nearly* 400 *feet deep in June of* 1840, *had been almost or quite obliterated.* However extravagant it may seem it was true. In the course of the next month, July, Rev. Chester S. Lyman (afterward Professor of Mechanics and Physics in the Sheffield Scientific School of Yale University), visited the crater and found it in the condition reported by Mr. Coan. The account of his investigations which he published states‡ that "the whole interior of the pit had been filled up nearly to a level with the black ledge, and in some places 50 to 100 feet above it." Moreover, Mr. Lyman proved that the change was not a change of level in the ledge, instead of the center of the pit, by measuring a base and taking, with a quadrant, the altitude above it of the high western wall, making it 680 feet, which agrees very nearly with the result of Wilkes's measurement.

Beyond all this, Mr. Lyman obtained full testimony as to *the way in which the rapid obliteration of the pit had gone forward.* He found that while the bottom of the pit was almost level with the "black ledge," there was upon it, *along the inner margin of the ledge,*" "a continuous ridge more than a mile in length consisting of angular blocks of compact lava, resembling the debris at the foot of a range of trap or basalt," and that this ridge had a height "on its outer or eastern face often of 50 or 100 feet [above the ledge], especially toward the south part,

against a survey. The crater Kilauea-iki is not named at all in Wilkes's map, unless "Lua-Pele" (a name of Kilauea) is intended for it. Mr. Wm. T. Brigham, on page 25 of this volume, expresses his confident opinion that the name Kilauea-iki (Little Kilauea) has become fastened to the wrong one of the two eastern pit craters. But it is used as here on the recent government maps, and was so used by Ellis in the earliest account of the crater; and it is the one of the two craters that is large enough to be so contrasted with Kilauea.

* My Expl. Exped. Report, p. 193. † Ibid.

‡ This Journal, II, xii, 75, 1851. A letter from Mr. Lyman, dated Sandwich Islands, July, 1846, is referred to on page 193 of my Expedition Geological Report, but no facts respecting the crater are there cited except the one that some parts of the center stand 100 to 150 feet above the black ledge; I have no knowledge of what it contained beyond this.

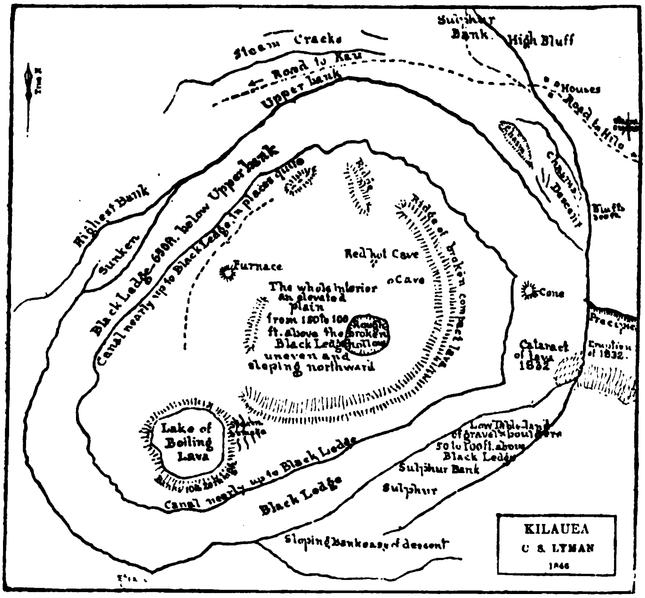
where it approached the Great Lake." Another remarkable feature of related import, was the existence generally of a trough, or "canal" as it had been called, between the ridge and the margin of the ledge, "several rods in width and in some places 40 or 50 feet in depth." The ridge looked highest from the black ledge side, the ledge being lower than the interior plain. Following it southward, the slope on the interior side diminished in height, and finally run out, while on the black ledge side, the elevation increased until the slope became a precipice over 100 feet high, which was so steep at "its southeastern limit that stones hurled from the hand cleared the foot of the bluff." The stones were "nearly three seconds in falling, which would give for the perpendicular elevation the amount just stated," [or between 140 and 150 feet.]

The "canal," as was learned from Mr. Coan, had been filling up, from a previous depth of 200 feet, by flows of lava from the Great South Lake. On one occasion the lake, "filled to the brim," poured out two streams, from "nearly opposite points of the lake," which followed the broad canal of either side, fifty or more feet deep and wide, "until they came within half a mile of meeting under the northern wall of the crater, thus nearly enclosing an area of about two miles in length and a mile and a half in breadth."* In 1846, it was nearly filled, and in some parts entirely obliterated.

After a survey of the facts as to the position and nature of the long ridge of lava blocks and comparing with the condition in 1840, Mr. Lyman concluded that the ridge "once constituted a *talus*, or accumulation of debris," on the floor at the foot of the walls of the lower pit of 1840; that the floor with its margin of blocks had "been elevated, partly by upheaving forces from beneath, and partly by overflows from the Great Lake and other active vents," until the talus overtopped "the precipice at the foot of which it was accumulated." He adds: "The phenomenon seems inexplicable on any other hypothesis than that of *the bodily upheaving of the inner floor of the crater.*" "When visited by the Exploring Expedition in 1840, the surface of the Great Lake was between three and four hundred feet below the black ledge and measured only 1000 by 1500 feet in diameter. Consequently in six years the lake had not

* Coan, Life in Hawaii, 1882, p. 263. Mr. Coan does not give the date of the event here mentioned; but no such "canal" is in the record except that of 1846. The time of the first recognition of the canal is not stated. It is certain that the "two deep fissures" of July, 1844 (Coan, this Journal, II, ix, 361, and my Exped. Rep., p. 193), were not the two sides of the canal; for they were opened "*under* the black ledge" and encircled "the whole *southern* area," while the Lyman canal encircled the whole interior of Kilauea. Further, as Mr. Coan says, these fissures around the southern area soon became filled with lava that was pouring over from the lake; while the "canal" was to a large extent unfilled in 1846.

only increased in size, but it had actually risen in height as much as it had been previously depressed by the out-draining of lavas in the eruption of 1840. This gradual rising of the solid embankment of the lake cotemporaneously with the lake itself, together with the filling up of the whole interior of the crater, is doubtless to be attributed to the combined effect of repeated overflowing together with the upheaving agency of subterranean forces."



Mr. Lyman took a few compass bearings in the crater, and some angles with a quadrant which he had constructed for the Kilauea visit, and left, with a friend on the Islands, a rapidly penned sketch of the crater showing the general condition of the interior. A reduced copy of the map with its lettering is here given. The chief discrepancy between it and the description is in the large interval between the "ridge" and the "canal," the latter being too near the outer wall. The "ridge," as is seen, is made to extend through half the circumference of the lower pit. The "Furnace," marked on the map, is described in his paper as oven-like, ten or twelve feet high, with walls a foot thick; as being inactive but showing within a glowing white heat early in July, but "in full blast" at his second visit in August, six weeks later. The large depression in the crater, which contained steaming fissures and chasms, appeared to have been the site of a former lava-lake.

The crater at the time of Mr. Lyman's visit was moderately active. The diameters of the Great Lake were 2400 and 2000 feet. Over its surface, ten or fifteen feet below the brim, on which he stood, the lavas were in gentle ebullition, tossing up broken jets 5 to 15 feet, and passing through frequent transitions between a crusted and a wholly molten state. It is evidence of relatively feeble activity that, standing on the brink, a handkerchief before the face was sufficient to shield it from the heat. In November of 1840, it was hardly possible to walk on the black ledge abreast of the lake, on account of the intense heat and light. The lavas had a general movement to the southwest. "A large stick of wood thrown on the lake, at a point where the ebullition produced a sort of eddy or rolling in of the lava, was immediately taken out of sight; but the next instant a more violent ebullition with a sudden outburst of flame and smoke told how, almost instantaneously, the stick had been transformed into charcoal."

The following year, in July, the Great Lake was boiling in much the same way as in 1846, with the liquid lavas still accessible, so that portions were taken out with canes.*

Early in 1848 the lake was the most of the time unusually inactive and became, as Mr. Coan states,† thickly encrusted over. The solid crust was soon after raised into a dome 200 or 300 feet high, covering the whole lake. By August, the dome was almost high enough "to overtop the lower part of the outer wall of Kilauea and look out upon the surrounding country." The fires within were visible through fissures; and occasionally lavas were ejected in sluggish masses, or forcibly, from several apertures or orifices of the dome, which "rolled in heavy and irregular streams down the sides," spreading and cooling over the slopes or at the base. "The dome, as it now stands," Mr. Coan wrote, "has been formed by the compound action of upheaving forces from beneath, and of eruptions from the openings forming successive layers upon its external surface."

This is the first account of a dome over Halema'uma'u; and the description and explanation of it agree with accounts of the most recent. During the most part of the year 1848, "no fire was to be seen in Kilauea, even in the night."

(2.) *Eruption (probably) of* 1849, *and changes from* 1849 *to* 1855.—After the events just mentioned, no important change in the crater is mentioned before the spring of 1849, when in April and May there was a return to great activity, and startling detonations were heard from the cones about the dome. The lavas were projected to a height of 50 to 60 feet from an opening in the top of the dome, and moreover the action

* Coan, this Journal, II, xii, 80, letter of Jan., 1851. † Coan, ibid., p. 81.

became so violent elsewhere that "travellers feared to descend into any part of the crater." This state of unusual activity was such as foreboded an eruption. It suddenly ceased, and probably by a subterranean discharge. It left the central plateau and the dome undisturbed; but the lavas were gone from Halema'uma'u and steam and vapors were the evidence left as to fires beneath.

A time of unusual quiet, of "steaming stupefaction," followed, and continued on through 1850 and 1851.* Early in 1852, the orifice at the top of the dome was 100 feet across and boiling lavas were seen within.† By July, this orifice had increased to 200 feet; and it was still enlarging by falls of great masses into the abyss 150 feet below, while steam and smoke were escaping from many holes in the sides of the dome, and lavas were ejected through a fissure dividing the west wall from top to bottom. Elsewhere the interior of Kilauea had little changed.‡ Mr. Coan predicted the speedy engulfment of the falling dome; but in the latter part of 1853 it was still standing, and probably was two miles in circuit, with a height of 300 to 600 feet.§

The great central plateau, surrounded by what used to be called the "black ledge" continued rising, and in 1853, its surface by Mr. Coan's estimate, was 600 feet above the bottom of 1840, and in part 200 feet above the ledge. His letter says "rising is going on" "first by the lifting forces below," "second, by eruptive overflowings; the former is more uniform and general, the latter, irregular and partial;" the former "in some places gradually, in others abruptly." Lyman's ridge of lava-blocks still existed little changed.

The crater continued "unusually dull" through 1854. The central plateau had been long out of reach of the fires, and ferns and Ohelo bushes were growing on it.

3. *Eruption of* 1855.—In 1855 a change to unusual activity occurred.‖ The lavas underneath the dome commenced throwing up jets to a height of 200 feet; vents were opened over the surface of the old black ledge; and thus in May and June the great central plateau had a girdle of fires nearly half a mile wide, in which Mr. Coan says he could count 60 lakes of "leaping lavas." There was one great lake at the foot of the north-

* Coan, this Journal, II, xiii, 397, 1852.

† Coan, ibid., xiv, 219, 1852, letter of March 5, 1852.

‡ Coan, ibid., xv, 63, 1863, letter of July 31, 1852.

§ Coan, ibid., xviii, 96, 1854, letter of Jan. 30, 1854. "The Island World of the Pacific," by Rev. Henry T. Cheever (8vo, New York), appeared in 1851, with an account of a visit to Kilauea. But the descriptions give no information of value, and the two plates relating to Kilauea (at pp. 287 and 307) are from Wilkes with large modifications in one and no acknowledgments; and with no statements that the view of the crater is an 1840 view—not 1850.

‖ Coan, this Journal, xxi, 100, 1856, letter of July 18, 1855, and p. 139, letter of Oct. 15, 1855.

east path down into the crater, and other "boiling caldrons" not far distant, so that access to the pit was cut off. The crater seemed to be ready for another eruption. On October 9th, the crater was still active, but less intensely so; the dome over Halema'uma'u had fallen in.

Mr. Coan's report of March, 1856, mentions several visits to the *summit-eruption then in progress*, but nothing about Kilauea until October of that year, when he speaks of the crater* as declining in activity for the year past, since the summit eruption began; "getting more and more profoundly asleep;" "only a little sluggish lava in the great pit of Halema'uma'u but much escaping vapor." A subterranean discharge took place probably in October, 1855.

4. 1855 *to* 1864.—In June of 1857 Kilauea was still quiet.† The lavas of the Great Lake were but 500 feet across and 100 feet below the edge. The alternations from the crusted to the completely molten state *took about three minutes.*

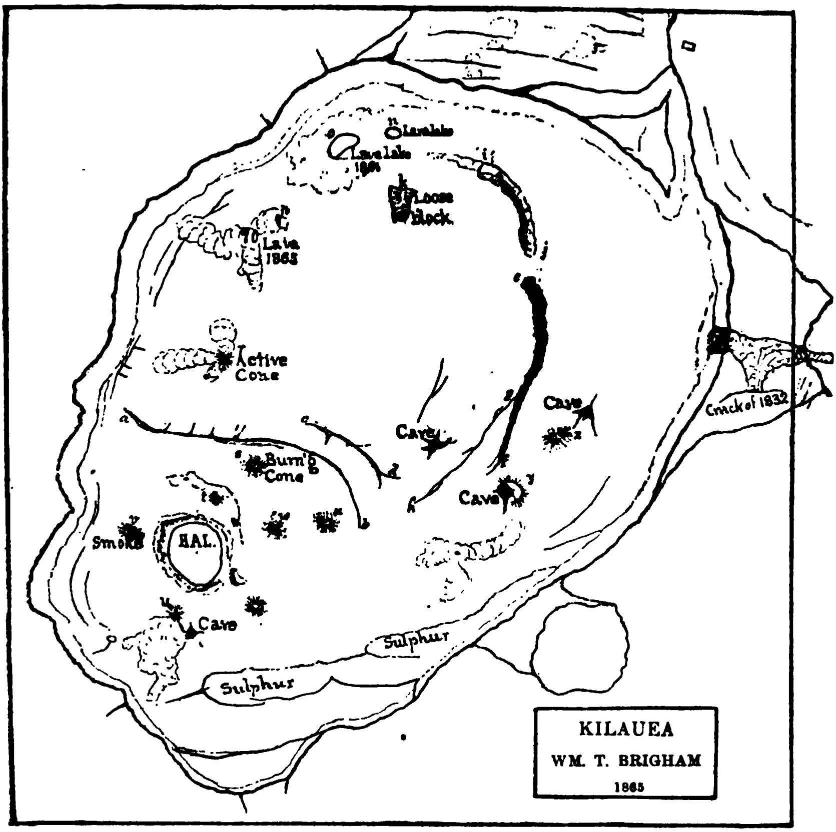
Through the following year, as during the two preceding, there was little change. In August, 1858, the Great Lake, some 500 feet in diameter, "boiled and sputtered lazily at the center of a deep basin which occupied the locality of the old dome." The action alternated between general refrigeration and a breaking up of the whole surface with intense ebullition."‡

In 1862, the condition was but little different. Halema'uma'u had a lake at center "about 600 feet in diameter." Within the basin, a fourth of a mile from the border of the lake at its center, there was a large mound of lava [a blow-hole product] with pinacles and turrets, somewhat cathedral like.§ In the summer of 1863,‖ activity had not much increased; at *intervals of a few seconds to half a minute*, a large fountain broke forth at the middle of the lake throwing up a rounded crest of lava 10 to 12 feet, and smaller portions to a height of 20 to 30 feet, while elsewhere there was a filmy crust through which small stones thrown in sank; and then again there was ebullition at various points in the lake: facts showing that the action was still far from brilliant.

In October, 1863, Mr. Coan reported new activity in the Great Lake, and through the whole circumference of the crater, with outflows that covered the old black ledge with fresh lavas. But the central plateau, "a distinct table-land," probably 500 to 600 feet above the bottom of 1840, remained unchanged.¶

* Coan, this Journal, II, xxiii, 435, 1857, letter of Oct. 22, 1856.
† Coan, ibid., xxv. 136, 1858, letter of Sept. 1, 1857.
‡ Coan, ibid., xxvii, 411, 1859, letter of Feb. 3, 1859.
§ Coan, ibid., xxxv, 296, 1863, letter of Nov. 13, 1862.
‖ O. H. Gulick, ibid., xxxvii, 416, 1864, letter of July 25, 1863.
¶ Coan, ibid., xxxvii, 415, 1864, letter of Oct. 6, 1863.

5. 1864–1866. *Observations and Map of* Mr. William. T. Brigham.—In 1864, Mr. Brigham visited Hawaii and began the observations on its volcanoes reported in his memoir. The accompanying copy (reduced) of the map made by him from his survey in 1865, deserves special attention. The map confirms the statements, made from 1846 onward, as to the obliteration of the lower pit. It shows the southwestern sulphur banks of much diminished extent since 1840, from lava over-



KILAUEA
WM. T. BRIGHAM
1865

flows. Halema'uma'u has apparently its old position, or is very near it. There are also, on the map, other lakes of small size; cones, two or three of which were of blow-hole origin, and one, *e*, named the Cathedral, from its half a dozen turrets (figured on p. 423 of the memoir) is that mentioned in 1862 by Mr. Coan (p. 88).

The map shows also two long pieces (*e f*, *i j*,) of Lyman's ridge of loose blocks of "compact broken lava," "concentric"

as Mr. Brigham reports, "with the main wall of Kilauea" "marking the limits of Dana's black ledge" [that is the black ledge of 1840]; "composed of fragments of all sizes and shapes, very solid and heavy, and full of small grains of olivine."

A recent letter from Mr. Brigham informs the writer that the ridge *i j* (which is not particularly mentioned in the report) had the same constitution as *e f*, but consisted of larger blocks.

Other interesting features, indicated on the map are (1) a wall, *a b*,—fault-wall—enclosing an amphitheatre, that of the Hale-ma'uma'u region, perhaps a result of a discharge at some unrecorded time of the lavas of the lake; (2) just north of this, a deep fissure *c d*, concentric with the wall *a b*; and (3) warm or hot steaming caverns in the floor of the crater, some of which were hung with gray-black, often tubular stalactites."*

The text states that in 1864 the "black ledge" region was fifty feet below the level of the interior plain of the crater, and that the difference in level was the same in May, 1866, although both had been much raised, "at least a hundred feet," the former by overflows and the latter without overflows.*

Mr. Brigham does not allude to Mr. Lyman's explanation of the long ridge of lava-blocks. He remarks as follows on p. 421, after stating the constitution of the ridge, as already cited: "This wall, which is concentric with the main wall of Kilauea, is said to rise and fall and sometimes disappear, which seems to be a fact, although no one has ever seen it in motion. It is the fragments broken from the edge of the crater by an eruption and floated out to its present position." Again, p. 415, "From a manuscript map prepared by Mr. Lyman, I find the ridge occupied the same position as at present." Again, in his account of the crater in May, 1866, p. 427: "The ledge of broken lava which swept around the eastern end of the crater, marking the limits of Dana's black ledge, is nearly covered with the successive overflows."

The Great Lake had a diameter of about 800 feet in 1864, and of 1000 in August, 1865. Its lavas in 1864 were 50 feet below the edge, and extended into caverns beneath it. The action was mostly feeble, "occasionally a crack opened and violent ebullition commenced at several points; again it was liquid, but soon passed to the viscid condition; again "boiling violently and dashing against the sides, throwing the red-hot spray high over the banks." There were two small islands in the lake in 1864; but in August, 1865, they had disappeared, and the lavas were then only 30 feet below the edge.

* The composition of the material of the stalactites, as given in the text, p. 463, from an analysis by Mr. John C. Jackson, is: Silica 51·9, alumina 13·4, iron sesquioxide 15·5, MnO 0·8, lime 9 6, magnesia 4·8, soda 3·0, potash 1·1=100. Specific gravity 2·9. The temperature of the caves was usually 80°–95° F.

The existence of flames over the large boiling lake is attested to by Mr. Brigham, who says (p. 423) speaking of a midnight view, that "they burst from the surface, and were in tongues or wide sheets a foot long and of a bluish green color, quite distinct from the lava even where white hot. They played over the whole surface at intervals, and I thought they were more frequent after one of the periodical risings of the surface."

In 1866,* there was a great increase of activity in Kilauea in May, June and July, beginning just after the cessation of the summit eruption. In May, new lakes of fire and cones were opened along a curving line extending from the Great Lake northwest to north and northeast, thus again covering the "black ledge" portion of the crater, flooding the surface with lavas for a distance of four miles, and with a breadth in some places of half a mile; and for days the flood of lavas closed the usual place of entrance to the crater. Large blocks were shaken down from the walls of Kilauea; and Mr. Brigham observes that these blocks were soon removed by the intensely active flood at their base, "showing how pit craters may be enlarged horizontally." In August the force of the eruption seemed to be spent—but no subterranean outflow is known to have occurred. During all the activity the central plateau of the crater remained undisturbed.

6. *Eruption of* 1868.—In 1868 a great outbreak and down-plunge took place in Kilauea, almost simultaneously with an erruption from the summit-crater of Mount Loa.† It was preceded by a succession of heavy earthquakes—two thousand or more according to reports—commencing on the 27th of March and culminating on Thursday, the 2nd of April, when a shock occurred of terrific violence, which was destructive through the districts of Hilo, Puna and Kau, northeast, east, south and southwest of Mt. Loa, and was felt far west of the limits of Hawaii. With the occurrence of this great shock, fissures were opened from the south end of Kilauea southwestward through Kapapala, a distance of thirteen miles, and bending thence southward toward the coast. The position of this line of fissures is shown on the large map of Hawaii published by the Government Survey in 1887; it followed the course of earlier fissures. Some lavas were ejected from the openings in Kapapala, which were probably lavas from Kilauea. Simultaneously with the

* Coan, this Journal, II, xliii, 264, 1867; Brigham's Memoir, p. 427.

† Dr. Wm. Hillebrand, this Journal, II, xlvi, p. 115, 1868; Coan, ibid., 106; F. S. Lyman, ibid., p. 109; H. M. Whitney, ibid., p. 112; Coan, ibid., xlvii, 89, 1869, letter of Sept. 1, 1868, with a map of southern Hawaii on p. 90. Also the same letters in a paper by Mr. Wm. T. Brigham, in the Memoirs Bost. Soc. N. Hist., i, 564, with a map on p. 572. The map was made by Mr. Brigham from his survey in 1865 and the descriptions of the 1868 eruption.

violent shock, a decline began in the fires of Kilauea. By night of that same Thursday, the liquid lavas had disappeared from all cones and were confined to the lakes; by Saturday night, all the lakes were emptied except the Great Lake; finally, by Sunday night, the 5th, the Great Lake had lost its lavas, and all was darkness and quiet. A down-plunge of the central plateau of the crater took place at the same time, so that again a lower pit existed, as in 1840. Mr. Coan, in describing it, says that the plateau "sagged down" 300 feet; and another writer, after a visit to the pit, gives the same depth and remarks "just as ice falls when the water is drawn from beneath." The great sunken area had not vertical walls, like that of 1840, but sloping sides as the term "sagged" implies; the slope, generally 30 to 60 feet, but at a much less angle on the side toward Halema'uma'u. There was again a black ledge, and it was nearly of its old width, but at a somewhat higher level owing to the overflows. The emptied Great Lake, 3000 feet in diameter at the top, 1500 feet below, and 500 feet deep, was literally empty; it showed no light at bottom by day and not much at night. The discharge of lava may have been as great as in 1840, although the lower pit made by the undermining had less extent.

Another remarkable fact is stated that just before the earthquake of the 2nd of April, "the lavas of Kilauea burst up vertically in Little Kilauea (Kilauea Iki), and spread over the old deposit of 1832."

On Tuesday, April 7th, five days after the beginning of the Kilauea discharge, the lavas were ejected in great volume at Kahuku in southwestern Hawaii, and flowed to the sea. It was at first a question whether a part of the Kahuku flow might not have come from Kilauea. But the extinction of the summit fires occurred at the same time, and the Kahuku discharge was in a line with fissures leading toward it from the summit, so that Mokuaweoweo is believed to have been their only source. The conduit of the Kilauea lavas, was probably ruptured at the time of the great shock, and hence the discharge.

The curving of the Kilauea fissures from Kapapala toward the coast seems to point to a submarine discharge off that part of the island.

3. Kilauea from 1868 to 1886.

This period of eighteen years passed without another down-plunge of the floor of the pit. The gradual filling of the new-made lower pit, and the ultimate merging of all slopes at the crater's bottom into those leading off in all directions from Halema'uma'u, are the chief events of the period. Mr. Lydgate's map on page 94, shows an intermediate stage in the progress.

1. *Changes from* 1868 *to* 1879.—After the discharge and consequent exhaustion of 1868, Kilauea was slow in its return to activity. In July of 1869, Mr. Coan found the crater quiet, and the basin of the Great Lake so nearly cooled that he went down into it, measured across its bottom 400 feet below the rim, finding it "five-sixths of a mile" wide, and at top more than a mile from the north to the south side. Down fissures over the emptied basin he could see the lavas, 50 to 100 feet below, still in ebullition.* Two years later† the Great Lake was full, and successive overflowings had covered deeply the southern end of the crater and sent streams two miles northward, filling the central pit to a depth of fifty feet. In August of 1871, Halema'uma'u was again a deep cavity, hot and full of dense vapors;‡ but before August of 1872, it was full with lavas and often overflowing into the great basin of 1868.

On March 3, 1873, Halema'uma'u, according to Mr. Nordhoff,§ was divided between two lakes, their shorter diameter about 500 feet; "the two were separated by a low-lying ledge or peninsula of lava; each was red, molten, fiery" within. From the "north bank" the depth of the pit or basin to the lavas was seen to be about 80 feet, and "the two large lakes appeared to be each nearly circular."

In January, 1874, says another observer, the lower pit was still much below the ledge. The surface of the Great Lake was 35 to 40 feet below the edge of the basin, and "possibly" 500 feet, by nearly half a mile in its diameters, but divided almost in two by a low bank of rock. Four months later, on the 4th of June, the cone about the Great Lake had risen much, and the lake was divided through into two oblong lakes, a north and south, in the direction of the longer diameter; it lay below precipitous and partly overhanging walls 80 feet high. The action was less intense than in January. There were active cones near by; 100 yards from the lake, one typical blowing cone "of beehive shape," 12 feet high, about 40 feet deep within, and having walls two feet thick, which was throwing up jets and clots of lava through holes in its sides, "with a deafening or rather stunning roar" and subterranean rumblings and detonations.‖

The following is a reduced copy of a map by Mr. J. M. Lydgate, made probably in June of 1874.¶ It has great interest,

* Coan, this Journal, III, ii, 454, letter of Aug. 30, 1871, and xviii, 227, 1879.

† Coan, ibid., ii, 454, 1871.

‡ Coan, ibid., iv, 407, 1872. Letter of Aug. 27, 1872.

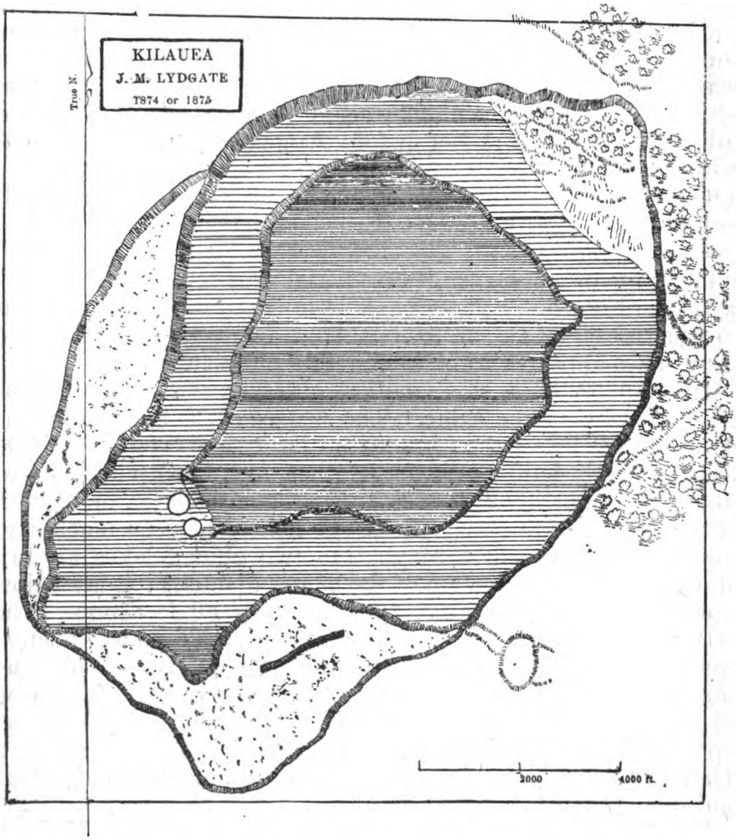
§ Northern California, Oregon and the Sandwich Ids. London, 1874.

‖ Isabella L. Bird, the Hawaiian Archipelago, London, 1875, pp. 55, 253.

¶ For this tracing I am indebted to the Surveyor General, Mr. Alexander, the original being in the archives of the office of the Hawaiian Survey. It is stated on it that the map was made either in 1874 or 1875, and probably in June, 1874.

since it shows the central depression or pit of 1868 still well defined, and also the subdivision of Halema'u'ma'u, above alluded to.

Mr. Coan states, early in October of 1874, that " the great central depression of 1868 has been filled up by deposits about 200 feet," and that the region around the Great South Lake was a truncated elevation nearly as high as the southern brim of the crater.*



2. *Eruption of* 1879.—In 1879 (April ?) Kilauea was again in eruption;† for the Great Lake, which had been running over, and whose rim had been raised till nearly as high as the outer edge of Kilauea, was suddenly emptied by a subterranean outlet and subsided several hundred feet, leaving nothing but a smoking basin.

* Coan, this Journal, III, viii, 1874, letter of Oct. 6, 1874.
† Coan, ibid., xviii, 227, 1879, letter of June 20, 1879.

After some days, in which there was no evidence of fires except that from escaping vapors and steam, the lava reappeared; and before May, 1880,* Halema'uma'u had again become a boiling and overflowing lake, pouring its streams into the great central basin of the crater.

In July of 1880, Mr. Wm. T. Brigham was again at the crater.† By barometric observations he made the depth to the northeast margin of the floor of the crater at the foot of the place of descent 650 feet below the level of the Volcano House; and the higher central portion of the floor, which was dome-shaped, was found to be 350 feet above the northeast margin, making the flat dome 350 feet high.

The "tolerably regular dome" was "surmounted by four lakes of an average diameter of a thousand feet." The latest of the four, the southeastern, commenced to form May 15th of that year, and its bank was in part nearly on a level with the lavas; but the others had stratified walls, as is stated and figured, which were in places 100 feet or more in height, and from their front there were frequent avalanches owing to the undermining action of the active lavas beneath. These lavas were seen here and there to be white-hot in the night view. In the darkness, "a large volume of gas" was observed escaping from a cluster of blow-holes in the vicinity of the lakes, "which burned with a bluish green flame," differing in its continuance from the flames seen before by Mr. Brigham, which "seldom lasted longer than a few moments."

The four lakes replaced old Halema'uma'u. By sighting from two of his monuments left from the 1865 survey, Mr. Brigham obtained evidence that the area of the old lake lay "in the midst of the present four lakes" instead of corresponding with either of them. This would make the summit, of the dome to be in the Halema'uma'u part of the crater, or its southern portion, as in 1886, the dome having in fact "a very eccentric apex."

In 1882, Captain Dutton made his examination of Kilauea. He states that after reaching the floor of the crater, he walked over the uneven surface for about a mile and three-quarters, and then came to a rapidly ascending slope, rising about 100 feet; and from the top of it looked down on "New Lake," about 480 feet long and 300 feet in width, lying between walls 15 to 20 feet high, situated to the northwest of Halema'uma'u. This lake first appeared, he states, in May, 1881.‡

* Coan, this Journal, III, xx, 72, 1880; letter dated May 3–6, 1880.
† This volume, p. 19, 1887.
‡ This Journal, III, xxv, 220, 1883, letter of Feb. 8, 1883; and U. S. Geol. Report, loc. cit.

New Lake was much of the time crusted over, showing fires only at the edges; break-ups, making cracks over the whole surface, and followed by an engulfing of the numberless fragments until "the whole was one glowing mass of lava," occurred at intervals of forty minutes to two and a quarter hours; but they were of short duration, and the lavas in the mean time were "quite black and still." Now and then a fountain broke out in the middle of the lake and boiled feebly for a few minutes; then it became quiet, "but only to renew the operation at some other point." The larger and more active lake, Halema'uma'u, half a mile off, was surrounded by a cone of loose lava fragments, the lavas a hundred feet below the top. The lake was to a considerable extent crusted over; but there were boiling fountains of liquid lava five to ten feet high (by estimate) in play, changing their positions from one part of the lake to another; one dying out as another started up. Two masses of solid lava were seen in the New Lake, looking as if formed in it, which in the course of several days shifted their positions, showing that they were floating islands.

3. *Eruption of* 1886.—These conditions continued, though with great variations, until March of 1886. On the 6th of that month, both Halema'uma'u and the "New Lake," (See Plates I and II, last volume), the latter five years old, were unusually full and active, and mingled their floods in overflows. The next morning, between 2 and 3 o'clock, the lavas disappeared and left both basins empty—first, the shallower New Lake, and then the Great Lake. The cone around the latter, then 200 feet in height above the boiling surface, fell into the emptied basin, and for days the down-plunge of the walls continued. The emptied basin, according to the measurements reported by Mr. Emerson, was about 2,500 feet in mean diameter, 560 feet in depth at center, and 200 feet in the depth of the precipitous sides except on the south. Mr. Emerson's map, Plate I of the preceding volume, represents the basin in its condition of exhaustion, and New Lake with its stranded floating island, standing 60 feet above its base. The map further shows, and also Plate II, by Mr. Dodge, that the great central basin of Kilauea, the lower pit of 1868, had been wholly obliterated, and all signs of the old black ledge. The lavas in the later years had swept over the whole surface, and placed Halema'uma'u at the head of all the slopes of the bottom, both the northern and the southern. The area around this lake-basin was left, as the map of Mr. Emerson shows, 350 feet below the level of the Volcano House, the center of Kilauea 356 to 400 feet below, and the bottom near the place of descent 450 to 485 feet. Mr. Emerson remarks, moreover (and the map indicates the same), that, with only a little more rise, the lavas of Halema'uma'u would discharge over the top of the southwest wall of Kilauea.

In July, four and a half months after the discharge, as Mr. Van Slyke reports, the emptied basin of Halema'uma'u contained within "a rising cone of loose rocks." The cone surrounded the central part of the basin, and consequently a great and deep trough-like depression several hundred feet wide separated it from the walls; it had a height in most parts of "perhaps 150 feet," and small cones and basins of lava existed at points in the trough around it.

Mr. Dodge's map and article (p. 99 of the preceding volume) represents the rising cone as 930 and 1,100 feet in its diameters, and as having some points in its summit as high as the edge of the basin—its condition in November, eight months after the eruption. Still later, in January,* he represents the cone of fallen blocks and lava debris as "perhaps 200 feet" above the height in October, and speaks of the rising as going on "slowly, *as though floating on the surface of the new lava-lake.*"

A "review of the phenomena, with conclusions" will complete this account of the changes in Kilauea since 1823; and, in the mean time, I hope to see the crater, in order better to understand its present and past condition..

[To be continued.]

* This Journal, xxxiii, 240, letter to the writer, dated Jan. 27, 1887.

[FROM THE AMERICAN JOURNAL OF SCIENCE, VOL. XXXIV, NOV., 1887.]

ART. XXXVIII.—*History of the Changes in the Mt. Loa Craters;* by JAMES D. DANA. (With Plates II, III, IV.) Part I, KILAUEA.

[Continued from page 97, vol. xxxiv.]

SUPPLEMENT.

A JOURNEY of ten weeks (involving over ten thousand miles of travel) has enabled me to carry out the purpose expressed in my communication of August last. I have thus succeeded in supplementing the work of that one day at Kilauea out of five on Hawaii to which I was restricted in 1840, by one week at Kilauea out of two on Hawaii, besides having one week for the extinct crater of Haleakala and other parts of Maui, an island not before visited, and two for the island of Oahu.

The original objects of the trip were: (1), to examine the great lava-lake of Kilauea, Halema'uma'u, in its existing state of moderate activity; (2), to re-examine the rocks and walls of the crater; and (3), to compare the lines in the Wilkes map with the present outline of the crater, in order especially to remove doubts about the map before using it as a basis for historical conclusions.*

In this supplement I present such of the facts from my observations on the islands as belong to the *history* of Kilauea, reserving the rest about the crater for the "Summary and Conclusions" which will follow in another number, and the observations elsewhere for a later number. I introduce also a few facts from other sources. For the convenience of reference the map of the Government Survey is here reproduced (Plate II).

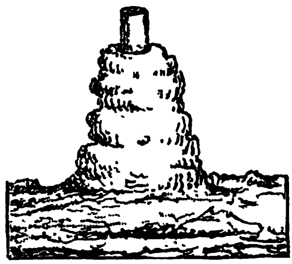
1. *Fissure ejections of* 1832 *and* 1868.—It is stated in early parts of this paper† that in 1832, and again in 1868, lavas were ejected through the depressed summit plain between Kilauea and Kilauea-iki. My observations enable me to state that Mr. Brigham's map, on page 89 of this volume, gives the position of the outflow of 1832, and the map of the Government Survey, Plate II, shows that of 1868. The lava of the latter stream has still a lustrous surface and little vegetation upon it, while the earlier has become weathered, and is much under shrubbery.

* I owe much of my success in the carrying out of my plans at the islands to Professor W. D. Alexander, Surveyor General of the Islands, Rev. Wm. C. Merritt, President of Oahu College, and Mr. J. S. Emerson, one of the assistants of the Government Survey, and am greatly indebted also to many others for kindnesses in various ways.

† Vol. xxxiii, p. 445 and this vol. p. 92.

The lavas of 1868 were ejected from a fissure nearly a hundred yards long, and flowed over the plain without descending into Kilauea, a portion of it covering part of the stream of 1832, as already stated. Many small trees standing in its course have now a rough cylindrical encasement of lava about their charred bases, which reaches to a height of from two to two and a half feet or more above the level of the flow, thus showing that the viscid stream, when reaching the trees on its way down the slope, had greater height of surface than afterward when the flow had passed by and its final level was attained.

1.



2. *Lower pit in* 1837.—The lower pit of 1832 had become very nearly obliterated, according to Mr. S. N. Castle, of Honolulu, by the latter part of August, 1837, as he informed me in August last. He found cones active in all parts of the crater.

3. *The "lower pit" of* 1868.—Mr. Nordhoff, in his "Northern California, Oregon and the Sandwich Islands,"* p. 45, says, speaking of the outbreak of Kilauea in 1868, "suddenly, one day, the greater part of the lava floor sank down or fell down a depth of about five hundred feet, to the level where we now walked. The wonderful tale was plain to us [March 3, 1873] as we examined the details on the spot. It was as though a top-heavy and dried-out pie-crust had fallen in at the middle, leaving a part of the circumference bent down but clinging at the outside of the dish." Mr. Nordhoff's statement as to the depth of the lower pit was evidently quoted, and is not independent testimony, but his comparison suggested by the sight of the place, sufficiently intelligible to an American, attests to the reality of the subsidence.

A letter from Mr. J. M. Lydgate, dated Laupahoehoe, Hawaii, August 10, 1887, contains the information that his map, reproduced on page 94 of this volume, was made after a survey in June of 1874. He also stated that the depth of the lower pit of 1868, was at that time, as nearly as he could now remember, "about thirty or forty feet where the trail crossed it."

4. *Level of the Great South Lake in January*, 1878.—Mr. C. J. Lyons, of the Government Survey Office, told me that on January 1, of 1878, he obtained, by means of a theodolite, 325 feet as the level of the lavas of Halema'uma'u below the datum mark at the Volcano House.

* 1874. New York and also London.

5. *Further testimony as to the eruption of* 1879.—The following testimony confirms the brief statement, on page 94, with regard to the fact of this eruption. It is from the hotel book of the Volcano House.

1878. July 20. "Halema'uma'u in a most active state." M. P. Robinson.—Sept. 20. "Very active." J. Mott Smith.—Nov. 24. "Very active; lava within a foot of top of bank."

1879. Jan. 8. "South Lake with lava 50 feet below the rim and boiling like water." Wm. Gardner.—March 19. "Large and bright lake."—April 15. "Light wonderful."

1879. April 21. "Bottom dropped out of crater." Wm. H. Lentz, of Honolulu.—Ap. 23. "Found the ——— thing extinct." G. Grœper.—Ap. 28. "Almost extinct; some vapors." Rev. A. O. Forbes, of Honolulu.—Ap. 29. "No fire at all." "Lake quite empty." J. Day.

1879. June 24. "Throwing up jets of lava; both lakes active; looks like a fountain of fire from the verandah of the Volcano House." Wm. H. Lentz.—July 2. "All traces of two lakes of July, 1878, obliterated, and instead an enormous single lake, which was quite active;" "lava thrown up 50 feet." Wm. Tregloan, of Honolulu.

The eruption was a discharge of the lavas of the Great Lake, as in that of March, 1886; and the lavas began to return in two months or sooner. Miss C. F. Gordon Cummings,* who was at the crater in the autumn of 1879, learned from others that the discharge took place on April 21st.

6. *Premonitions and effects of the eruption of March*, 1886, *in the vicinity of the Volcano House.*—The situation of the Volcano House is shown on plate II. It is within the great area of subsidence, northeast of Kilauea, where are many fault-plane precipices and numerous open fissures, many of the latter discharging freely hot air and steam, fumarole-like, and some of the deeper sending up also sulphurous acid gas. The large depressed area adjoining the house on the west is a true Solfatara, and the well-known extensive sulphur bank within it,—the only real sulphur bank about Kilauea at the present time—is hardly four hundred yards distant. A bathing house for vapor baths is near by, which is supplied with hot vapors from one of the fissures. The proprietor of the house, Mr. J. H. Maby, informed me that on the afternoon of the 6th of March, (Saturday) wishing to take a bath, he found at repeated visits the vapors at the bath-house too hot for it, and finally gave it up. At 9^h $30'$ of that evening a slight earthquake was felt, and at 9^h $45'$, three others, which made "thud-like sounds," or

* Fire Fountains of the Kingdom of Hawaii, 2 vols., 8vo, London, 1883.

"like the fall of a meal-bag on the floor." At 10^h the light over Halema'uma'u, before very brilliant, suddenly disappeared; the discharge had taken place. Through Sunday morning the escape of vapors from the fissures of the Solfatara region near the Volcano House went on, but it ceased entirely on Tuesday, and the stoppage continued through Wednesday and Thursday. Afterwards the discharge was gradually resumed.

The forty-one earthquakes which are reported as having occurred during the night, though not strong enough to shake down furniture in the house or crockery from shelves, felt to Mr. Maby as if the foundations of the house were giving way. The shocks have been attributed to the down-plungings of the walls of Halema'uma'u; but the intervening distance, 12,000 feet, is too great for such an effect; moreover, deep fissures were opened near by, along the road just east of the Volcano House, which are still steaming, and these suggest a sufficient cause.

The following facts are from the author's recent observations.

7. *Contrast in activity between the second week in November,* 1840, *and August* 11 *to* 18, 1887.—In November, 1840, the crater, over a very large interior region, including that of Halema'uma'u, was nearly a thousand feet in depth, and to the black ledge, or terrace, 650 feet. *Now*, as Messrs. Emerson and Dodge have reported,* the floor is everywhere less than 500 feet below the level of the Volcano House; the central part is but 400 to 360 feet; the Halema'uma'u border mostly under 340 feet; and, further, the floor slopes in all directions from Halema'uma'u to the base of the cliffs. The lava streams cover up all debris at the base. A few stones were observed imbedded in the lava that must have fallen during the flow before the lava had cooled.

In 1840, the Great South Lake—situated at the bottom of a southern prolongation of the lower pit nearly half a mile wide—was in fiery ebullition throughout, throwing up vertical lava-jets to a height of thirty feet or so over a surface of 1000 by 1500 feet; and it was so brilliant that at night the projecting angles and jetting points of the lofty black walls of Kilauea were lighted up throughout the whole circuit of the pit, and so hot as to forbid approach within 250 yards. *Now*, the Halema'uma'u basin, while a little over half a mile in mean diameter,* has at center a black and gray cone made of lava blocks and earth (as described by Mr. Dodge), sending forth vapors freely from apertures about it, but affording no signs of liquid lavas within; for even in a night view the clouds of vapors were

* This Journal, last volume, (pages 87, 98).

lighted up not over the cone, but east and west of it. Figure 2 is a view of the cone without its vapors, taken from the Vol-

2.

Cone in Halema'uma'u.

cano House; it is seen to rise out of an abrupt depression, which is that of Halema'uma'u. The narrow part of the depression to the left is the basin of the adjoining "New Lake." Plate III, representing the north end of the cone, with the bottom of the Halema'uma'u basin outside of it, illustrates its agglomerate nature. It is literally debris-made, and the debris is chiefly that from fallen walls, not the cinders or loose scoria derived from the ejections of a central vent. The plate shows also the character of the wall of Halema'uma'u, the stratification in the wall of Kilauea, and, above the latter, snow-capped Mt. Loa. The photograph from which the plate was engraved was taken in January last.

The only lake with active fires that was open to view in August last, was that on the west side of the cone; the more southern and the southeastern borders were swept by the wind-drifted vapors. The lake was but 150 by 175 feet in its diameters. It was mostly crusted over, but showed the red fires in a few long crossing lines (fissures), and in three to five open places, half way under the overhanging rock of the margin where the lavas were dashing up in spray and splashing noisily, with seemingly the liquidity of water. Now and then the fire places widened out toward the interior of the lake, breaking up the crust and consuming it by fusion; yet at no time was there a projection of the lavas in vertical jets in a free-boiling way; nor was it too hot to stand on the border of the lake if only the face were protected. Although relatively so quiet, the mobility of the brilliant splashing lavas made it an intensely interesting sight. Occasionally the red fissures widened by a fusing of the sides as the crust near by heaved, and the lavas flowed over the surface. It was evident from the cooled streams outside, that now and then more forcible movements take place, followed by outflows over the margin.

8. *The ordinary lava-stream, Pahoehoe of the Islanders.*—The ordinary Kilauea lava-stream made by overflowing or outflowing of the thoroughly fused lavas is remarkably smooth in surface. This is well seen in the small overflowings from the lava-lake, the lavas being so liquid that it may be dipped up

with a ladle or even a spoon.* But through one way and another it usually becomes uneven in general surface, wrinkled, billowy, hummocky, knobbed, fractured, and sometimes caved in or shoved out of place when fractured; and other rough features come from the adding of stream to stream. Plate IV shows something of the uneven character, but not the larger irregularities. Part of these rough features are owing directly or indirectly to crusting by surface-cooling, thinly or deeply, during the flow. Wrinkles, "billows" or domes, knobby and ridgy surfaces are depended on this condition, as well as the tunnel-like chambers and many of the shallower fractures. The fractures often lead to displacements of masses, and also to outflows of lava. In these outflows, the still liquid lava beneath the crust oozes out and fills the crack and so makes a seam, the immediate cooling at surface preventing a further flow; or the lavas pour out in larger volume and spread away in streamlets. Or the crust yields at a thin spot and the liquid stuff pushes out, but becomes at once stiffened and stopped by cooling and so makes projecting knobs of various sizes, shapes and lengths. Another source of uneven surface and cracks is the moisture beneath the flowing lavas of the crater, which is always present at greater or less depths since rain falls every other day or oftener.

The wrinkles and dome-shaped elevations or "billows" are remarked upon beyond.

The "pahoehoe" of Kilauea is of two kinds: (1) the ordinary lava of the mountain-side; and (2) that of the crater, distinguished by its separable scoriaceous glassy crust. The crust is a *crater*-feature, for I have not seen it on the lavas of the mountain outside. The crust, at the present time, is half an inch to two inches thick, and thickest in the vicinity of Halema'uma'u. As before described, it separates easily from the stony lava underneath; and this is so because the vesicles along the plane of junction are much larger than elsewhere.

The stony lava beneath the glassy crust, making the body of the Kilauea streams, and many feet or yards thick is remarkably solid, having relatively few vesicles. Moreover, this light gray to black basalt contains commonly very little chrysolite (olivine). The most chrysolitic which I observed in Kilauea rocks was from one of the layers near the bottom of the precipice in Waldron's ledge, 100 feet or so above the level of the Kilauea floor. The stratified lavas of the *walls* of Kilauea, so far as examined, have the same compact stony character as those of the bottom, the same sparing distribution of air-vesicles. Some of the kinds, of light gray color, are almost wholly free from vesicles. But while the upper part of a layer in the walls is sometimes scoriaceous, it is never covered with a glassy crust.

* I have a spoon filled with lava that was dipped up by Mr. Coan.

The lavas exuded through the crust from the liquid mass below, above alluded to as making seams, streamlets and knobby surfaces, are covered sometimes with separable scoriaceous glassy crust, though commonly having a solid glassy exterior half an inch or so thick.

9. *The wrinkled surfaces or tapestry-like folds of the flowing lavas.*—While looking at the small lava lake, the making of the tapestry-like folds, so common a fluidal feature of the lava-streams of Hawaii, was well exemplified. A stream of lava came out from beneath the cone and flowed obliquely across the lake, making the folds or wrinkles by its onward movement in the thin crust which surface cooling had produced; and the wrinkles were convex down-stream because of the greater velocity at centre. The accompanying figure repre-

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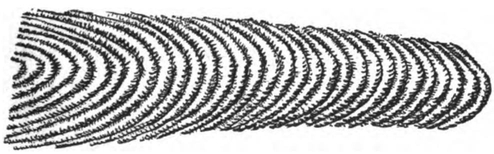


sents, reduced, a small portion of the stream. At one time a lateral shove took place along one of the fissures in the crust of the lake, and the next moment the margin was rolled over into a long fold or wrinkle, and then by the more rapid movement of the middle portion, a large part of the fold became twisted into a rope. Thus fold may follow fold, and make a group or series of rope-like folds; and tapestry wrinkles become rope-like by a similar method.

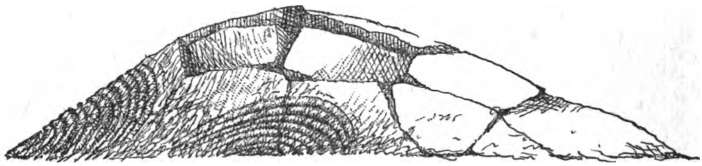
The tapestry-like folds of the surface of streams are sometimes folds simply in the scoria-crust; but they commonly consist of the more solid lava also, or of that alone where the scoria-crust is absent. This rope-making goes on over parts of outflowing lava streams. Sometimes, in connection with the making of the long ropes, the crust, where thin, becomes bent upward so as to have a long empty space a foot or two deep beneath the brittle cover. It is a trap for the incautious traveler, but it usually startles without injuring, yet serves to point a paragraph about the dangers of the crater.

On Plate IV, which represents the general aspect of the floor of Kilauea (and of many lava flows elsewhere) there are examples of the tapestry-like folds, and some of the small folds are twisted rope-like.

10. *Dome-shaped bulgings of lava-streams made sometimes, if not generally, after the stream has flowed on.*—Such bulgings, the

"billows" or "hummocks," in part, of some describers, are common here and there over a stream and often have a height of fifteen to twenty feet. I have attributed them, in my Exploring Expedition Report, to steam made from moisture underneath. This view is sustained by the actual arching of the stratum, often seen in a cross-section, and also by the cavity or cavities within and the broken or fallen-in top. Some seem to have been further crushed by the push of a subsequent lava flow.

4.



The sulphur vapors may also aid in making these dome-shaped elevations. And when so, the space below may have, as the facts show, the roof covered with a crust and stalactites of glauber salts, or with a thin crust of gypsum; the vapors having contributed material for the sulphuric acid, and the labradorite of the lavas, the soda or lime.

In many places evidence was plain that bulging had taken place after the flow of the lava-stream though before complete consolidation. This evidence was afforded by the tapestry folds on the bulged surface, they being upside down; that is, the folds were often convex upward instead of downward, as in the figure. The tapestry folds indicate the direction of movement; and, when thus upside down, they prove that they had been turned out of their original position.

11. *Flames from the lava-lake.*—The party which made a night visit to the small lava-lake in Halema'uma'u, the evening before we left the place, saw flames, similar in all respects to those reported by Mr. Brigham.* They were seen to rise where heavings and breakings of the lava-crust took place, and not where the fires were most active. The flames were one to three feet in height. They were very pale in color and slightly greenish rather than bluish. I cannot claim myself to have seen the flames—the rains of the evening, and a cold from a thorough wetting the day before, having prevented my joining the party. But critical observers were of the number—as Mr. Emerson of the Government Survey, President Merritt of Oahu College, Rev. S. E. Bishop and others, and the testimony was unanimous.

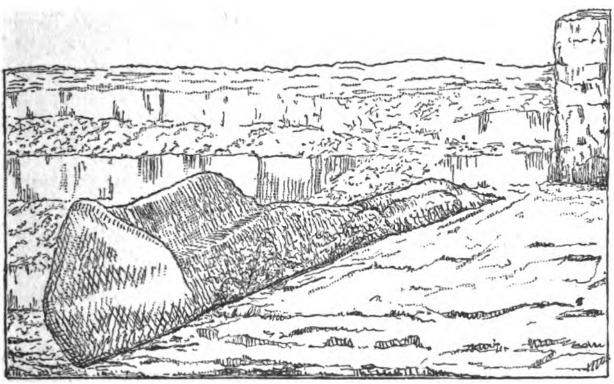
* This volume, pages 91, 95.

12. *Floating Island of* 1882 *to* 1886, *now stranded.*—Mr. Emerson speaks of the stranded floating island of New Lake as over sixty feet high, and describes well its surroundings.* I found, from an early photograph, that not long after it began its floating career it had the form shown in the following figure, as if it were a portion of a solidified lava-stream, either taken

5.

from the sides of the lake, where undermining by the dashing and fusing lavas might have separated it, or more probably derived from depths below and floated upward by the rising lavas. An examination of the stranded island showed that it consisted of the ordinary Kilauea lava, not much vesiculated, but enough to enable it easily to float. Further, it indicated great change in form since its first appearance. It lies on the bottom of the emptied lake-basin, as seen in the following figure (taken from a photograph). Two other photographs

6.



which I obtained at Honolulu, show intermediate forms, but they do not differ greatly from figure 5 above. The change in form might have come both from the projection over it of liquid lavas, and from erosion of its sides by the fusing heat. It is not known how much of it was beneath the surface of the lava; but the reader may perhaps satisfy himself on this point.

13. *The fissured borders of Kilauea.*—Besides the great fissures of the northern border of the crater, near the path of

* This Journal, xxxiii, 91, 1886.

descent with the subsided belts between, and the many fissures of the Solfatara depression just back, others occur farther north and east, to a wall, about forty feet high, which is evidently a fault wall. This wall is about 2000 feet from Kilauea at the northwest corner, and diverges eastward to about 5000 feet, and then bends around southward so as to embrace Kilauea-iki within the large northern border region of fissures and subsidence.

Deep and wide rents extend also along the whole western border of Kilauea, generally two or more together; and near the highest station, Uwekahuna, there are six of them parallel to one another. South of this station, between it and the southwest angle of the crater, the fissures are continued over a large depressed border 500 to 1,500 feet wide, lying between a precipitous ridge—fault-plane—on the west and the crater. North of Uwekahuna the evidences of subsidence now visible are small; but south of it the surface has different terrace levels, showing great and various sinkings of the surface. Almost in front of Uwekahuna, bordering the Kilauea wall, there is a surface, 200 to 298 feet below the level of this station, according to the Government maps, which is plainly, as seen from below, a result of subsidence; and various other terrrace-levels exist farther south. On the east side of Kilauea, also, there are fissures parallel to the walls; and large depressed areas exist between Kilauea and the two adjoining craters. Fissures extend northward to the east of Kilauea-iki, as noticed by the Wilkes expedition in 1840, and new openings there, near the Keauhou road, were reported as opened in March, 1886, at the time of the eruption.

The wall on the northeast side of Kilauea, near the path of descent, called Waldron's ledge (after a purser in the Wilkes expedition) is one of the highest and most stable parts of the walls, being but eleven and a half feet below the level of the Volcano House datum. It is a bare-faced, vertical precipice, showing stratified lavas to the top. Like Uwekahuna, it seems to be an exception to border instability. But it stands on the brink of the most unstable region—that of the north side. In a walk along the base of the precipice I found a fresh uncovering of the rock at bottom for a height of two to three inches, showing that a recent sinking adjoining it had taken place, or that one was then in progress.

This border belt of fissures and subsidences, if reckoned as part of the Kilauea fire-region, or region of disturbance, adds 5000 feet to the length of the region, and nearly doubles the width across the northern half.

There are long fissures also, over the region southwest of the crater, some of which were reported by the Mission Deputa-

tion of 1825. It is an interesting and important fact that while the fissures about the northeast end of Kilauea are *concentric* with the outline of the crater (Kilauea-iki being included with it), those at the south end are nearly all *longitudinal*, or in the direction of the longer diameter, southwestward. Moreover, as is well known, they extend on for twelve to fifteen miles to the southwest. They are very numerous, more so than is shown on any map or recorded in any description; and some are very deep in places, giving off hot air, steam and sulphurous acid fumes in great volume. While some of them date from 1868, and others from 1886,* still others existed back of all records.

The subsidence that has gone on over this southwestern fissured area has not left any satisfactory evidence of its amount. We know only, that (as the Government map teaches) the surface is about 280 feet below the level of the Volcano House and 395 below that of the Uwekahuna station.

14. *Volcanic sand, stones and scoria, covering all the borders of Kilauea, from an eruption about the year* 1789.—The account of the eruption of 1789, gathered from the natives by the Rev. I. Dibble and published in his "History of the Sandwich Islands"† (1843), mentions that for two nights there were eruptions with ejections of "stones and cinders;" soon followed the rising of a dense, dark cloud from the crater, with thundering and lightning, and then "an immense volume of sand and cinders which were thrown to a great height, and came down in a destructive shower for many miles around."

The "sand and cinders" of this eruption (the latter usually called on the island *pumice*,‡ on account of its extreme lightness, and first mentioned by Ellis, who says "light as a sponge") are well known to cover an area of "many miles" to the southwest of the crater; but the accounts of the region have said nothing about the stones until the publication of Professor C. H. Hitchcock in Science of February last, after his visit to the crater in the summer of 1886. He there reports that:

"Standing at Keanakakoi, one sees to the southwest and south a stretch of volcanic sand and débris fully equal in dimensions to Kilauea itself. On examining more closely the material called 'gravel' on the map, it was seen to consist of material

* Mr. Emerson distinguishes the two sets in his paper in the last volume of this Journal. An exact mapping and numbering of all the fissures, as well as determination of levels, about the Kilauea border would be a very important step toward a correct reading of the future history.

† The facts which Mr. Dibble publishes are cited in my Expl. Exped. Report, on page 183.

‡ Pumice is the scoria of a trachytic or some orthoclase-bearing lava, with the vesicles linear.

ejected from the volcano, and numerous lava-bombs were picked up. Ashes also cover the country to the south and southwest over the Kau desert for several miles."

But it is still not appreciated that Mr. Dibble's words "many miles around" are true if made to include the whole circuit of Kilauea, even the vicinity of the Volcano House, and that the projection of stones preceded that of the light scoria ("pumice"), as Mr. Dibble's account says; yet was itself preceded by a great shower of volcanic ashes or sand. The facts show, moreover, that the stones are in great numbers and of large size to the west and northwest of the crater. The deposit has its maximum thickness over a large area south and southwest of the crater, where it is twenty-five to thirty feet thick and extends ten miles or more away. It is well exposed to view along the fissures. The lower twenty to twenty-five feet of the deposit consist of yellowish brown beds of tufa, the material very fine volcanic sand and hardly consolidated. Above the tufa are two to three feet of a coarse conglomerate consisting chiefly of stones; and above this stratum, a bed twelve to sixteen inches thick of closely packed brownish sponge-like scoria ("pumice"), in pieces half an inch across to two or three inches.

This sponge-like scoria contains the least possible amount of solid matter, being about ninety-eight and one-third per cent air, the rest glass; for the small round cells have no walls except a few slender threads, and it is about as light as a dry sponge. On account of its lightness it is easily carried off by winds as well as the sleepiest of waters, and hence the bed is often left in patches.

The ejected stones vary in size up to several cubic feet. Those of one to two cubic feet are common, many are 20 to 30, and one seen on the west side measured 100 cubic feet and must have weighed over eight tons. Part are ordinary volcanic scoria; but the most of them consist of the more solid basalt sparingly vesicular; and many of the larger are of a light-gray kind very slightly vesicular or hardly at all so, only slightly chrysolitic, and frequently having on the worn exterior a faint banded appearance from alternating variations in compactness of texture. Another kind varies in color from faintly reddish to gray, is more or less vesicular, and contains a large amount of chrysolite—suggesting the nature of a bomb, though not having an exterior shell.*

Going from the southwest border northward and approaching the highest point on the west side, the Uwekahuna station of the survey, the deposit becomes thinner, but retains well its

* The rocks collected on Hawaii have not yet arrived and hence only general descriptions are here given.

characteristics. North of this station the thickness becomes ten feet and less. At the Volcano House it is six feet or more. It may be seen in front of the house at the first descent, where it includes, at bottom, a bed of pebbles; upon this, six to eight inches of the spongy scoria ("pumice"); then another pebbly layer and some fine tufa. It occurs also just north of the Volcano House garden and may be found in traces elsewhere about the north border.

From the south border of the crater the formation extends around by the east side not only to Keanakakoi,* but to the Kilauea-iki depression, thinning northward as on the west side, but having the same characteristics, as observed in the spongy scoria, the great numbers of large stones and the kinds of rock constituting them. But the stones, though many and large, are of somewhat less size than to the west and southwest, and the "pumice" to the northward on this windward side of the crater is in thin widely scattered patches. The tongue of land extending from that side toward the south end of Halema'uma'u, with the words over it on the map "gravel and boulders," owes its gravel and many bowlders to the same source, as Professor Hitchcock implies. The low plain between Kilauea-iki and Kilauea fails of it; but this is owing to recent lava out-flows over the surface. The deep soil and earth farther east over a region crossed by the north and south carriage road by which we made the ascent to the crater, bearing tree-ferns, etc., in luxuriance, is probably an eastern portion of the tufa formation.

The greatness and violence of the eruption cannot be doubted. Its distribution all around Kilauea seems to show that the whole bottom of the pit was in action; yet the southern, as usual, most intensely so. The heavy compact rock of the stones and the size of many of them indicate that the more deep-seated rocks along the conduit of the volcano were torn off by the furiously ascending lavas. It was a *projectile* eruption of Kilauea such as has not been known in more recent times.

I looked along the walls of Kilauea to ascertain whether there was evidence of earlier eruptions of the kind, but found

* The name *Keanakakoi* or Keana-ka-koi, applied on the Hawaiian Government map to the small crater east of the southern half of Kilauea, signifies, as I was informed by an intelligent native, the *chipping-stone pit*, and refers to the fact that formerly a very compact grayish lava was obtained at its bottom and used there for the manufacture of stone implements. No such stone or manufacture has ever existed at Kilauea-iki. This appears to settle the question as to the correct application of the latter name raised by Mr. Brigham. The crater has now a bottom of very smooth recent lava, which our guide stated had been ejected 8 or 10 years back; which suggests that the ejection may have occurred at the time of the eruption of 1879.

no such beds of tufa or conglomerate, and no tufa or sand beds of any kind intervening between the beds of lava constituting them. There are fresh-looking lava-streams over the slopes of Kilauea southwest of the crater, but none appeared along the route to Punaluu of more recent date than the cinder deposit.

15. *The aa lava streams.*—The *aa* areas, looking like ploughed-up lava streams on a majestic scale, occur in the course of outflows of both Kilauea and Mount Loa, and a small area of the kind now exists (see map) in the floor of Kilauea. Several of them were seen on the way up from Keauhou to Kilauea; one about ten miles from Kilauea in Kapapala, near the road to Punaluu, three near Punaluu on the southern border of Hawaii, and one on the lava stream of 1881, within six miles of Hilo. The coarsest and most characteristic of them are those near Punaluu; and that near Hilo has special interest. In crossing Hawaii in 1840 I was over others between Punaluu and Kaulanamauna. My new study of them has led me to a change of opinion as to their mode of origin and to an explanation not yet on record. The description which follows will give others an opportunity to speculate about them.

An *aa* or *arate* lava stream consists of detached masses of lava, as far as is visible from the outside. The masses are of

7.

very irregular shapes, and confusedly piled up to nearly a common level, although covering often areas many miles long and half a mile to a mile or more wide. The size of the masses in the coarser kind varies from a few inches across to several yards. The rock constituting the body of the mass is the ordinary solid lava, usually little vesiculated, not the scoriaceous; but the exterior surface is roughly cavernous and horridly jagged, with projections often a foot or more long that are bristled all over with points and angles. In some cases ragged spaces ex-

tend along planes through the large masses, like those of the exterior. But in these as in other parts, it is evident that the agency was tearing and up-ploughing, and cavity-making in its action, and not vesiculating. At one place great slab-like masses of very compact rock, 20 feet or more long, stood vertically together, each about 8 feet high and 3 to 10 inches thick, with a curving over at top, somewhat like gigantic shavings. Ellis, in the "Journal" of the Hawaiian tour of the Mission deputation in 1825, appears to describe similar occurrences over the *aa* fields in the following words:

"Slabs of lava from 9 to 12 inches thick and from 4 to 20 or 30 feet in diameter, were frequently piled up edgewise or stood leaning against several others in a similar manner. Some of them were 6, 10, or 12 feet above the general surface."

These piles of jagged rocks have usually a height of 25 to 40 feet above the level of the adjoining smooth-surfaced stream, owing this height evidently to the large spaces among the blocks.

The above figure represents the features of such a stream. The title of such piles of blocks to the name of a stream would not be admitted were it not proved that they are formed during the progress of a lava-flow; that a lava-stream may change from the smooth-flowing or (pahoehoe) condition to the *aa*, and back again to the smooth-flowing; and that the same vent may give out at one and the same time, a smooth-flowing stream in one direction, and an *aa* stream in another. The Mt. Loa stream of 1880–'81, is mostly a smooth-surfaced stream; but over part of it, within six miles of Hilo (where I went under the guidance of Rev. E. P. Baker, a close student of the Hawaiian volcanoes), the pahoehoe stream changed for a few hundred yards to *aa*, with evidences of transition between them. Further, Mr. Furneaux, an artist, informed me, in his studio at Honolulu, that he was at the head of the flow of 1880, on Mauna Loa, when it was in progress; that one of the three streams which was then flowing from the vent—that going southeastward—was of the *aa* kind, while the other two were smooth-flowing or pahoehoe; that he saw the *aa* stream very gradually advancing, the sides apparently motionless, but about the front, now and then a block tumbling down from above; and the blocks toward the foot at intervals making a shove onward, and rather gaining on the bottom portion where there was impeding friction; and he noticed a red heat between some of the blocks in the front portion. He had in his studio a painting of the scene.

In some *aa* streams, however--probably the thinner streams—the masses are much smaller and more scoria-like than above

described; and these graduate into broken scoriaceous lava-flows.

In two of the *aa* streams near Punaluu the lava is but slightly chrysolitic; in a third somewhat more recent stream, situated not a mile farther west, the lava is very abundantly chrysolitic. All the facts appear to show that there is no connection between kind of rock and kind of flow.

16. *The enormous bomb-like masses of some aa streams.*—The bombs, as they might be called, of the *aa* streams are, inside and out, in striking contrast with the other masses. Many of them occur in the Kapapala stream, and also in those near Punaluu. They are smoothish exteriorly, more or less rounded and bowlder-like; and they vary in size from a mean diameter of a few inches to ten feet and more. One of them is represented in the *aa* picture at the top to the right (p. 362).

Some of these bombs consist outside of a crust, four to six inches thick, of hard grayish, slightly vesicular basalt, and *inside* of fragments of reddish or grayish scoria, the shell being packed full of the scoria fragments. In others similar, the scoria was partly rolled up. Some of them consisted of concentric shells, hard and scoriaceous shells alternating with one another. One had a nucleus of scoria 18 inches in diameter; and around this, successively, a stoney shell of 3 inches; a scoriaceous layer of 1 to 2 inches; a stoney shell of 4 to 5 inches, and then, outside, a rough lava shell 6 inches thick. One of large size, broken open on one side, had had its inside filling of scoria worked out by the natives, and so made into a small cave.

A common size is three to five feet in diameter: but one enormous bomb, in the *aa* field west of Punaluu, measured $24 \times 12 \times 9$ feet in its extreme dimensions, and contained at east 1,000 cubic feet. Enough of its hard outer shell was pealed off to ascertain that the second layer was much vesicular or scoriaceous, and the next layer inside, hard basalt again.

These bombs lie in the midst of the other blocks of the *aa* stream, proving that all had a common origin, and *that they are not projected bombs*, and hence, properly, not bombs at all.*

The further discussion of the phenomena of Kilauea is left for the "Summary and Conclusions."

[To be continued.]

* The word *a-a* is pronounced as if written *ah-ah*, the vowels in all Hawaiian words having the Italian sounds; *au* has the sound of *ow* in English. Kilauea has an accent on the *e*, and Haleakala on the *a* before the *k*. *Pahoehoe* means smooth and shining, and its use is not confined to lava.

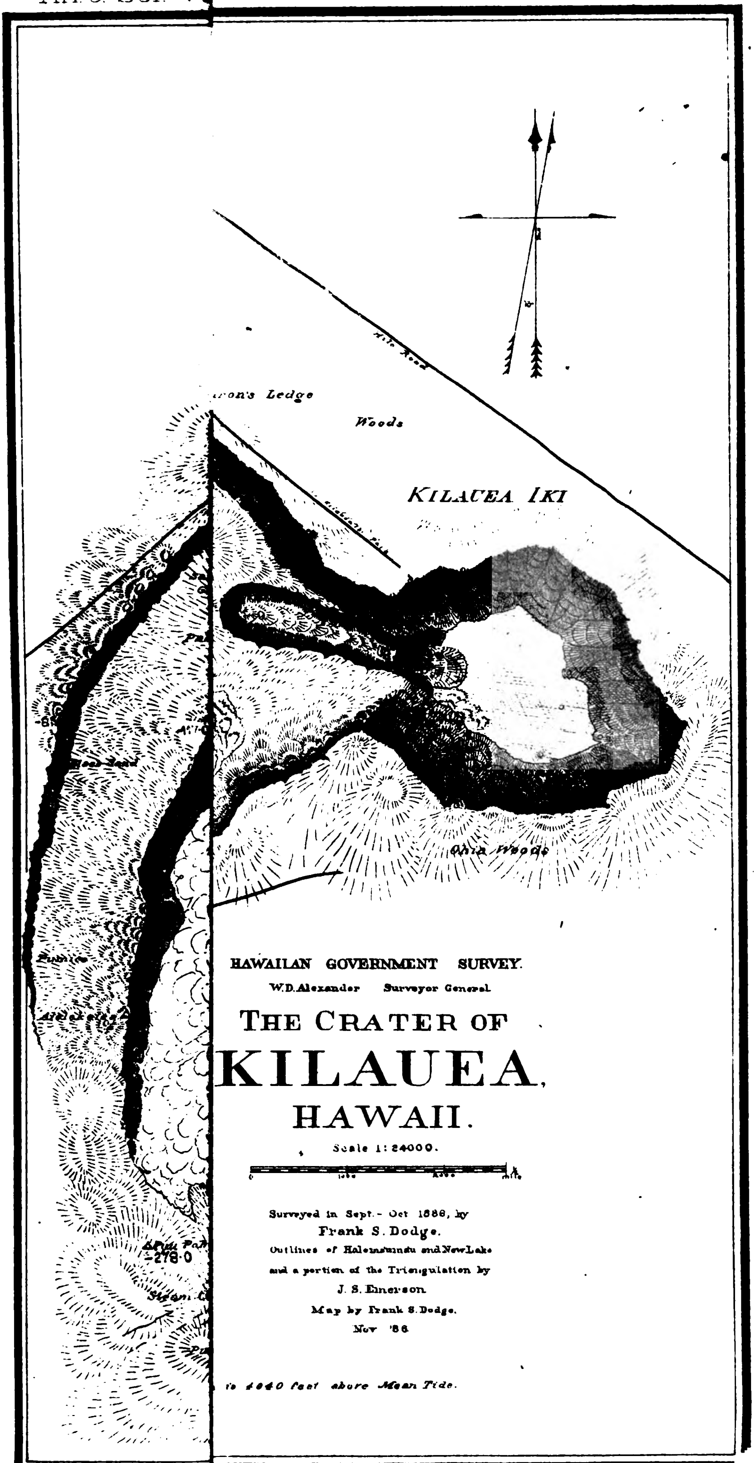


Photo Lith. L.S. Punderson, New Haven, Ct.

North end of the Halema'uma'u basin and of the debris-cone within it; and above the west wall of the basin, the walls of Kilauea and the dome, Mt. Loa.

LAVA FLOOR OF KILAUEA.

[From the American Journal of Science, Vol. XXXV, Jan., 1888.]

Art. II.—*History of the changes in the Mt. Loa Craters*; by James D. Dana. Part I. Kilauea. (With Plate I).

[Continued from vol. xxxiii, p. 433 (June), vol. xxxiv, p. 81 (August), and p. 349 (November).]

4. General Summary, with Conclusions.

From the foregoing review of publications on Kilauea, it appears that we have already much real knowledge about the changes in the crater, and that this knowledge embraces facts that are fundamental to the science of volcanic action. This will be made more apparent by the Summary and Conclusions which follow. It will be convenient to consider, first, the Historical conclusions, and secondly, the Dynamical.

I. HISTORICAL.

1. *Periodicity or not in the discharges of Kilauea.*

In the sixty-three years from 1823 to 1886, there appear to have been at least eight discharges of Kilauea. Four of them were of prime magnitude—those of 1823, 1832, 1840

and 1868—distinguished by a down-plunge in the floor of the crater making in each case a lower pit several hundred feet deep. Others, as those of 1849, 1855, 1879, 1886, were minor discharges, discharges simply of the active lakes, without any appreciable or noticed sinking of the floor of the crater. The eruption of 1849 might be questioned; but it was preceded by far more activity in the crater than that of 1886. Other subterranean discharges may have occurred since 1840 of which no record exists. Even small breaks below might empty Halema'uma'u.

The mean length of interval between the first three eruptions was 8 to 9 years (xxxiv, 81). The great eruption of 1789, the only one on record before that of 1823, occurred 34 years back of 1823, or $4 \times 8\frac{1}{2}$ years; and the 1868 eruption was $3 \times 9\frac{1}{3}$ years after that of 1840.

The above approximate coincidences in interval and multiples of that interval seem to favor some law of progress. But it is not yet proved that they have any significance. The minor eruptions which have been referred to above have intervals varying from 6 to 13 years. Moreover, looking to the summit crater of Mt. Loa for its testimony, we find still greater irregularity, the successive intervals between its six great outflows from 1843 to 1887 being 9, 4, $3\frac{1}{2}$, 9, $12\frac{1}{2}$, $6\frac{1}{4}$ years.

A partial *dependence of the activity of the fires on seasons of rains* was suggested by Mr. Coan; and there is some foundation for the opinion in the times of occurrence of the Kilauea discharges mostly within the four months, March to June, as shown in the following table:

1823	March?	1855	October.
1832	June (Jan.?) (xxxiii, 445)	1868	April 2.
1840	May.	1879	April 21.
1849	May.	1886	March 6.

In addition, there was a brightening of the fires around the crater in October of 1863; and again in May and June of 1866; whether followed by a discharge of the Great Lake is not known. The future study of the crater should have special reference to this point.

2. *Mean rate of elevation of the floor of the crater after the great eruptions.*

After the eruption of 1823, between the spring of that year and October of 1829, an interval of $6\frac{1}{2}$ years, the bottom, if the depth was 800 feet as inferred after the measurement of the upper wall by Lieut. Malden, rose at a mean annual rate of 138 feet, or, taking the depth at 600 feet, of 93·3 feet. Lieut. Malden's 900 feet for the upper wall,

sustained, after explanation (xxxiii, 440), may need reduction on the ground that the present width of the crater is greater than in 1825, owing to falls of the walls; but it is useless with present knowledge to make any definite correction. Only general results are possible.

After the 1832 eruption, the lower pit in February of 1834, was 362 feet deep, by the barometric measurement of Mr. Douglas,* and in May of 1838, about 4½ years later it was filled to within 40 feet of the top; whence the mean annual rate of 71½ feet.

After the 1840 eruption, between January, 1841, and the summer of 1846, 5½ years, the 342 feet of depth, found for the lower pit by the Wilkes Expedition, was obliterated, and the floor was raised on an average 40 or 50 feet beyond this; a rise of 400 feet in the 5½ years would give for the mean annual rate, 72¾ feet.

Subsequent to 1846 the rising of the floor was slower. Between 1846 and 1868, 22 years, the rise over the central plateau is estimated at 200 feet. It is not certain that subsidences in the plateau of greater or less amount did not take place at the eruptions of 1849 and 1855, or at other times.

3. *Levels of the floor after the eruptions of* 1823, 1832, 1840, 1868 *and* 1886.

The measurements of depth already given and the mean annual rate of progress deduced are approximate data for determining the depth of the lower pit as it existed immediately after the great eruptions.

The depth after the 1823 eruption is considered above. To arrive at the depth after the 1832 eruption, the depth obtained in 1834 by Douglas has to be increased by an allowance for change during the previous year and a half, which, at the rate arrived at above, would give 450 feet. This is so much less than the estimate of Mr. Goodrich (xxxiii, 446) that it is almost certainly below rather than above the actual fact. For the depth in June 1840, the Wilkes Expedition measurement, 342 feet, should be increased for a preceding interval of seven months, which at the rate deduced above for the next four years, would make the amount about 385 feet. In 1868, according to the two estimates for the lower pit (xxxiv, 92), the depth was about 300 feet. Mr. Severance of Hilo, informed me in August last that the pit in 1868 was as deep as in 1840. The lower estimate is adopted beyond. In 1880, the lower pit of 1868 had wholly disappeared, and, according to

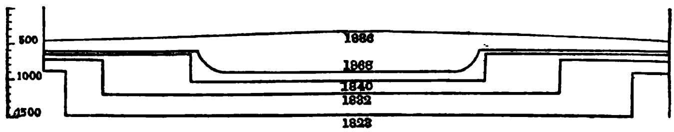
* See the first part of this paper. vol. xxxiii, p. 446, June, 1887, where the facts are definitely given, and also other evidence.

the description of Mr. Brigham (xxxiv, 95, from page 20 of the same volume) the bottom of the crater had already the form of a low eccentric cone, the surface rising from the foot of the encircling walls to the summit about Halema'uma'u. This has continued to be the form of the bottom, and the Government map gives the present depth. (See the accompanying Plate I).*

The following table contains (A) the above deduced figures for the depth of the lower pit; (B) the height of the *highest part* of the western wall; and (C) the level of the center of the pit below the top of the western wall.

	Depth of Lower Pit.		Height of W. Wall above ledge.	Height of W. Wall above center of bottom.	
After eruption of 1823	600	(800?)	900 (?) Malden	1500	(1700?)
1832	450	(600?)	715 Douglas	1165	(1315?)
1840	385		650 Wilkes †	1030	
1868	300		600 (550?)	900	(850?)
1886	0		500 Govt. Survey	380	

These numbers have much instruction in them notwithstanding all uncertainties. The following diagram, based on them, represents a transverse section of the crater at the several levels of the floor and black ledge. The minimum depths for 1823 and 1832 are here accepted, there being in them no probability of exaggeration.



The sides of the pit in this section are made vertical from 1823 onward—an error which there are no data for correcting.

* Mr. Brigham's paper gives results of his barometric measurements in 1880, that are not reconcilable wih those of the Government or of earlier determinations except on the assumption of great changes of level between 1880 and 1886 and small difference of level as regards the base of the cone between 1840 and 1880. His depths are 650 feet at the northern base of the cone near the place of descent, where Wilkes made the depth 650 feet, and the Government map in 1886, 481 feet; and 300 at Halema'uma'u, where the Government survey made the depth nowhere less than 320 feet. By the reported measurements, the cone had a height of 350 feet in 1880, and of 150 in 1886; accordingly the base of the cone to the north had been raised 140 feet in the 6 years after 1880 while nothing or little in the 40 years preceding it, although large overflows during the interval, adding 50 to 100 feet to its height, are mentioned by Mr. Brigham and others; and the level about Halema'uma'u had lost 30 feet between 1880 and 1886. The latter difference of level is not impossible; but the former it is natural to question, since so great a rise of the border in 6 years could not have taken place by any method without being noticed.

† The Wilkes Expedition appears to have made the place of encampment the datum point. The exact position of the place is not precisely known. It may probably be ascertained nearly enough to give by leveling the height with reference to the Volcano House; but at this time the height has not been determined.

The diminution since 1823 in the height of the western wall above the black ledge is probably due almost wholly to the *flooding* of the black ledge. According to the numbers, this diminution was about 185 feet from 1823 to 1832; 65 from 1832 to 1840; and 160 feet since 1840. But subsequent to 1840, as Emerson's map shows, the diminution of level along the black ledge or lateral portion of the pit has been much less than over the central, the amount of diminution at center having been at least 200 feet, and about Halema'uma'u 250 to 300 feet.

The bottom of the emptied basin of Halema'uma'u after the eruption of 1886 was 900 feet below the Volcano House; and this was 50 to 100 feet above the liquid lava of the basin in 1840.

The relations between the amounts discharged in 1823, 1832, 1840 and 1868 could be approximately inferred from the size of the lower pit as determined by the mean breadth of the black ledge, if the width of the crater were the same at all periods. But in addition to other uncertainties we have that arising from sloping walls, and very sloping on the southeast side. The pit of 1823 should therefore have been narrower at the black-ledge level than that of 1840. Still, the width of the ledge in 1823, according to all the observations and maps, was so very narrow compared with that in 1840, that we may feel sure of the far larger amount of the earlier discharge. But the depth of the lower pit was also greater in 1823, and this requires an addition of one half to the amount which the area of the lower pit suggests, if not a doubling of it.

For an estimation of the discharge of 1832 we are still more uncertain as to the mean width of the ledge. But that the ledge was narrow, much like that of 1823, is most probable. In 1868 the down-plunge, according to the most reliable estimate, was a fourth less than in 1840, the depth of the pit being not over 300 feet.

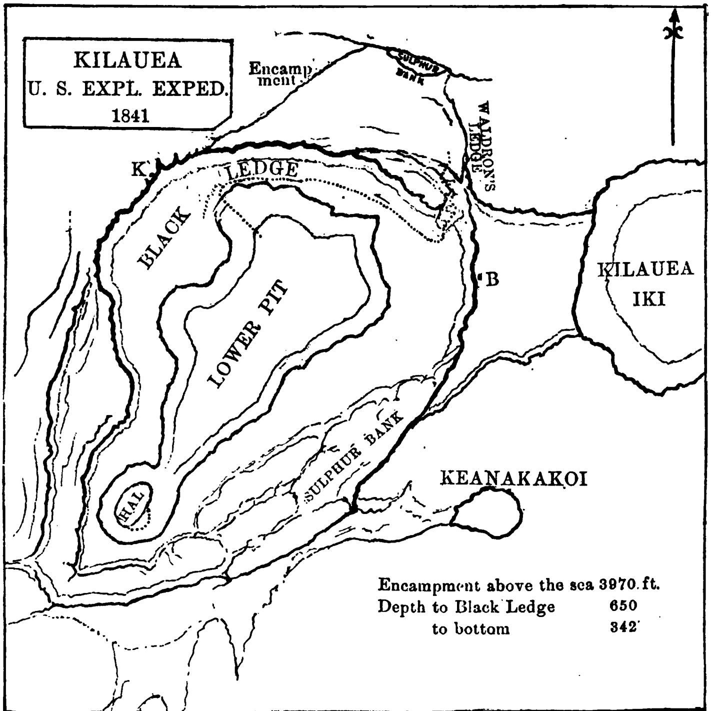
There are no sufficient data for putting in figures the relative amounts of discharge at the great eruptions. But the general fact of a large diminution in the amounts since the first in 1823 is beyond question. It has to be admitted, however, that we can hardly estimate safely the discharge in 1868 from the size of the pit then made, since the thickness of the solid floor of the crater may have prevented as large a collapse in proportion to the discharge. But it did not take place until 28 years had passed after 1840, and this strengthens the evidence as to an apparent decline in the outflows, whatever be true as to the activity. The following eighteen years produced only minor eruptions.

4. *Other points in the Topographic history of the Kilauea region.*

Besides the points considered, the chief events in the topographic history since 1823 are: (1) avalanches and subsidences

along the border of the crater; and (2) overflowings and changes of level over the bottom.

Down-falls of the walls and sinkings of the borders are reported as having been common during periods of eruption and earthquake; but direct testimony as to the amount at any time does not exist. In view of the great numbers of deep fissures about Kilauea (xxxiv, 358) and the many fault-planes and sunken areas, the fact cannot be doubted; and Mr. Brigham has estimated* that the crater in 1880 was five per cent larger than it was 18 years before. The increase in mean diameter on this estimate would be 300 feet. I think the estimate large.

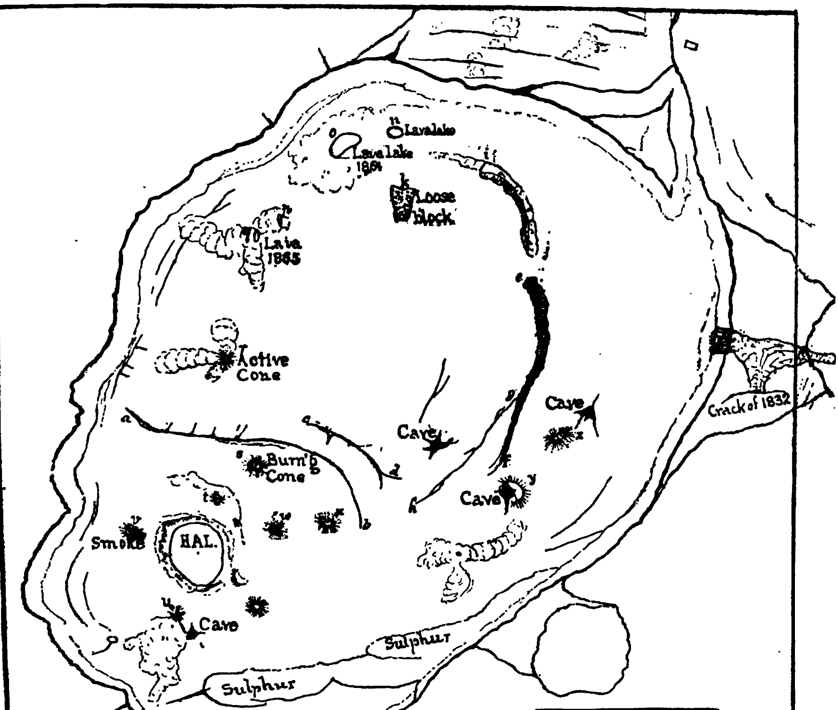


Of the gradual changes over the bottom of the crater pretty full records have been gathered from the published accounts. But we naturally look with the greatest confidence to the maps that give the results of personal surveys, especially with regard to changes in the outline of the walls. We have two such maps—that made personally by Wilkes in 1841, and that by Brigham in 1865, besides the recent map by the Hawaiian

* This Journal, III, xxxiv, 20.

government, under Professor Alexander's charge, completed in 1886. For convenient comparison the reduced copies of Wilkes's and Brigham's maps are here reprinted; that of the Government survey is reproduced in Plate 1 of this volume.

In using the maps a difficulty is encountered at the outset in consequence of a discrepancy between the first two of the maps and that of the Government survey as to the dimensions of the crater. Accepting the latter as right, the scale of each of the others should be diminished about an eighth to bring the three



KILAUEA
WM. T. BRIGHAM
1865

maps into correspondence. The maximum diameters in Wilkes's map, using his own scale, are 16,000 and 11,000 feet; while according to the Government map they are about 14,000 and 9800 feet; and the length of the line from K to B on the former is 10,000 feet and on the latter 8500 feet. It is certain that the crater in 1840 was not *larger* at top than now. Mr. Brigham's map appears to have been carefully made, but for

some reason it requires the same correction. Such a discrepancy unavoidably throws doubts over other parts of the maps. But while closer study increases confidence in Mr. Brigham's, the result is not so satisfactory with the Wilkes map. The following remarks suppose the scale of the two maps to have been corrected.

Wilkes's map of Kilauea.—The relations of the map made by Capt. Wilkes to that of the Government Survey is exhibited on Plate 1, the outline of the crater from the former being drawn over the latter where it is essentially divergent. This diverging part of the outline is lettered A B C D E, D E showing the outline of the sulphur banks of 1840. Besides this, the outline of the black ledge of 1840 is indicated by the line L L L, and its surface by cross-lining. Some important features from Brigham's map also are drawn in and indicated by italic letters. These include small lava-lakes, the outline of Halema'uma'u as given by him, small cones, fissures, etc.

The plate shows, in the first place, a general conformity between the eastern wall of the Wilkes and Government maps, but a far greater width of sulphur banks in that of 1840. These sulphur banks have become submerged by the lava flows of later time, and thus the floor of the crater has in this part been extended eastward about 2500 feet. Of this I believe there is no doubt.

In the second place, there is no conformity between the maps in the southern half of the western wall. Instead, on Wilkes's map, south of the Uwekahuna station, the west wall (A B C on Plate 1) is 1200 to 1500 feet inside of the position of the existing wall as given on the Government map; showing, apparently, a very great topographical change on that side of Kilauea since January, 1841, and one of the highest interest; a change either by subsidence, or by overflowings of lava streams, adding nearly 10,000,000 square feet to the area of the crater.

Looking about for other evidence of this change, and finding no allusion to it in Mr. Coan's reports, and nothing in Mr. Lyman's paper or map of 1846 (xxxiv, 83), but, on the contrary, a general conformity in Lyman's map to that of the recent survey, I was led to question the unavoidable conclusion, although it involved a doubt of the Wilkes map. A consequence of the doubt was my sudden determination to revisit Hawaii and sustain the conclusions from Wilkes's map if possible; for they made too large a piece in the history to be left in doubt. Mr. Drayton's sketch, reproduced as Plate 12 in a former part of this paper (xxxiii, 437), suggested the method of deciding the question.

The conclusion arrived at while on the ground in August last, was that Drayton's sketch represented sufficiently well the *existing* outline of that part of the crater, that is, of the crater of to-day. It follows, consequently, that the west wall of 1841 and of 1887 are essentially alike in position, and that Wilkes's map of the southern half of its western wall is 1200 to 1500 feet out of the way.

To make this large correction on Wilkes's map involves some other large changes; namely, the widening greatly of the black ledge west of Halema'uma'u; and also a probable widening of the Halema'uma'u part of the lower pit with the entrance-way to it. Both changes are favored or required by Drayton's sketch. The entrance-way referred to is thus widened (on the ground of Drayton's sketch chiefly), from Wilkes's 800 feet at top of wall to about 1500 feet. The dotted line L'L'L' on Plate 1 is believed to show the probable limit of the 1840 black ledge along the west border of Halema'uma'u.*

So large an error in so small a map excites an uncomfortable query as to all the rest of its details; fortunately not, however, as to the depth of the crater and its lower pit, since this was obtained by the independent measurements of two of the Expedition officers, Lieutenants Budd and Eld. Moreover the map may be used for some general conclusions.

Drayton's sketch was probably taken from the point marked *Dn* on the map, south of Wilkes's encampment, or on the higher land to the west of this point.†

The sketch has three headlands along the west wall. Of these, only the second and third exist as they then were. The first or nearest stood, as the sketch shows, between the Uwekahuna summit and the second of the deep western bays on Wilkes's map of the lower pit, a spot where great subsidence has taken place in the western wall, east or southeast of the Uwekahuna station (xxxiv, 358); and the sketch appears to be sufficient testimony for the reality of this subsidence and its amount.

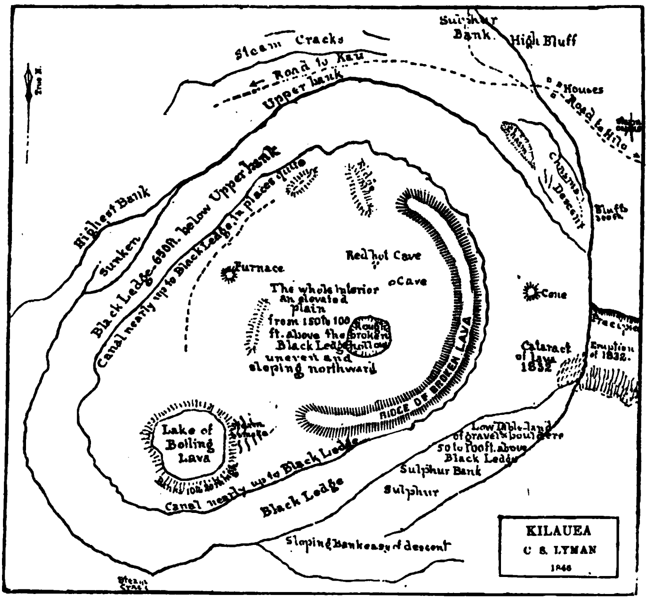
Looking again at Wilkes's map (page 20), it is seen that, as already stated, the outer *eastern* wall has the same position that it has on the Government map, but that the *southeastern* wall of Wilkes is not continuous with his western, but is an independent one situated more to the eastward; and here came in the error. The error is so extraordinarily great that we sought while at the crater for some extraordinary excuse for it. We concluded (Mr.

* Another smaller change is proposed in the eastern outline of the lower pit, near *e*, suggested by Brigham's map. No attempt is made to give on the Government map Wilkes's outline of the southeast angle of the crater, as the existing features offer no available suggestions.

† While the sketch bears evidence of being generally faithful to the facts, the foreground appears to be modified for the artistic purpose of giving distance to the rest.

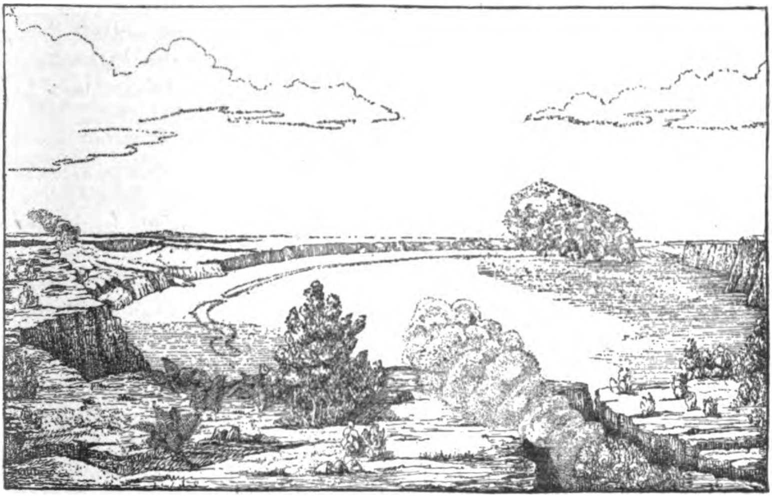
Merritt and myself) that Captain Wilkes in his visit to "all the stations around the crater in their turn" (xxxiii, 451), on reaching the high Uwekahuna summit, instead of relying on his angles, probably took the shorter way of sketching in the ridges that stood to the southeast and south; and that he was led by insufficient topographical judgment to throw the wall, together with the parallel ridge outside of it, too far to the eastward. The error, as we saw when there, is an easy one for him to have made. This cramped the map to the southward about the Great South Lakes, but the angles taken from other stations were not enough to serve for the needed correction and the sketching was allowed to control the lines. However this may be, it is lamentable that a correct map, with a careful determination of heights around the crater, was not made in 1840.

An important error also exists in Wilkes's determination of the longitude of his encampment near the crater. The Surveyor-General of the Islands, Prof. Alexander, informed me that the position Wilkes gives Kilauea is 8½ minutes too far west; and that the error affects all the southeastern quarter of his map of Hawaii including the position of the coast line. His longitude of the summit of Mt. Loa is correct.



Mr. Brigham's map.—Mr. Brigham's map is a register of the facts of 1864–65, a period just half way between 1841 and 1887. It indicates unfinished changes in progress within the crater which were commenced in 1840, and other conditions that became pronounced only in later years.

The remnants it represents of Lyman's ridge of lava-blocks, —the talus of the lower wall uplifted upon the rising floor of the lower pit—has already been referred to (xxxiv, 89). That it may be fully appreciated, the reader is directed again to Mr. Lyman's map, here reprinted with corrections by him;* and then to Plate 1, which shows these remaining parts of the long ridge drawn, from Brigham's map, on the recent map of the Government survey (lettered *ef*, *gh*). The ridges are not put as far from the east wall of the crater as on Brigham's map, but are made to accord with the statement of each Lyman and Coan, and of Brigham also, that they followed the course of the lower-pit wall of 1840 a little inside of its position, over the site of the original talus—Wilkes's position of the wall being adopted except for a short distance near *e*. Halema'uma'u, as



the dotted line inside of the basin of the Government map shows, was small in 1864–65, it being only 1,000 feet in diameter and but little raised above the level of the liquid lavas.

The preceding additional view of the crater is introduced at this place because it contains the remains of the Lyman ridge as mapped by Mr. Brigham, and is further testimony as to its

* The copy of Prof. Lyman's map, reproduced on page 85 of the last volume of this Journal, is not from a tracing of his original map, but from a roughly drawn copy left on the islands. The original was lost by him, as he informs me, when in California on his return to New Haven. He has here placed the "canal" along side of the ridge, in accordance with the statement in his description and also in his note-book of 1846, which makes the interval between them "10 to 40 and 50 yards." Before publishing the map I endeavored to obtain corrections from him. But on account of his illness at the time I could not communicate with him.

position with reference to the walls. The view is from a photograph of a painting made by Mr. Perry, a California artist, in 1864 (?) the year of Mr. Brigham's first visit, and which I received from Mr. Brigham in March, 1865.* The sketch of the crater bears evidence throughout of great accuracy of detail. It has much interest also because it gives, with clear definition, the outlines of the depression (on the left) between Kilauea and the side crater Kilauea-iki;—in which respect it is more satisfactory than Drayton's sketch. The point of view was on the north border of Kilauea, a little to the east of Drayton's; and consequently it necessarily differs widely from Drayton's sketch as regards the headlands of the western wall, yet resembles it quite closely on the eastern side. Halema'uma'u is not defined; and this is explained by Mr. Brigham's map and description.

Mr. Brigham's map shows also the positions of active lava-lakes in 1864 or 1865, lettered *i*, *k*, *l*, *m;* and the interesting fact is to be noted that two of them, to the northwest, *i*, *k* lie *at the edge of the black ledge*, while *l*, *m* are a little back of it, but in a line with *i*, *k*.

The long curving line of deep fissures and fault-plane, already referred to as marking the outline of the Halema'uma'u region, is seen on Plate 1, at *a b*, not to be concentric with the Halema'uma'u basin of either Brigham's map (p. 21) or of the recent map; but to that of Halema'uma'u *plus* the New Lake region of 1884 to 1887. Thus in 1865, when Halema'uma'u appeared as a small basin 1,000 feet broad (not half its existing breadth), the fissure indicated the presence of deep-seated conditions as to the fires and forces, that finally ultimated in its extension over the New Lake area. And the expression of this fact in 1865 was doubled by a second concentric fissure 500 feet farther north (Plate 1, *c d*). Further, four of the cones mapped by Brigham in the vicinity of Halema'uma'u in 1865, *p*, *q*, *r*, *s*, on Plate 1, are inside of the existing Halema'uma'u basin; and one of the others, *o*, is near the north border, and another, *t*, is close by the east side of New Lake.

On Mr. Brigham's map, the position is given of a very large loose block of lava, which is shown at *w*, on Plate 1. It lies, as is seen, in the northwest part of the crater, and is over the lower edge of what in 1840 (see Wilkes's map, p. 20) was an inclined but even lava plain to the bottom that had been made in 1840 by an oblique down plunge (xxxiv, 82) carrying the inner side of the great mass down and leaving the other, that against the black ledge, on a level with the ledge, with a broad

* See Brigham's Memoir, page 419, where a wood-cut from it is introduced, but without doing the photograph justice. Mr. Brigham does not state in his memoir the date of the painting. "Perry" is mentioned as the painter on page 468.

fissure between. The block probably slid down the slope to its bottom; and, as the talus at the bottom of the lower wall was lifted on the rising floor to make Lyman's ridge, so it appears that this loose block was lifted in the northwest corner; and the lift along that part of the crater consisted in the restoring of the half engulfed mass with the lava-block on its surface, to its former horizontal position—the position it had when Mr. Brigham's map and observations were made.

It is interesting to note thus how the 1864–1865 condition of Kilauea grew out of that of 1840, and foreshadowed that of 1887. It is worthy of consideration also that just as the fault-plane *ab* is concentric with the Halema'uma'u basin *plus* New Lake, so the far greater Kilauea fault-planes, 2000 to 5000 feet north and northeast of the crater (xxxiv, 358), are concentric, not with Kilauea, but with Kilauea *plus* Kilauea-iki.

2. DYNAMICAL CONCLUSIONS.

General cycle of movement in Kilauea.—The history of Kilauea, through all its course since 1823, illustrates the fact that the cycle of movement of the volcano is simply: (1) a rising in level of the liquid lavas and of the bottom of the crater; (2) a discharge of the accumulated lavas down to some level in the conduit determined by the outbreak; (3) a down-plunge of more or less of the floor of the region undermined by the discharge. Then follows another cycle: a rising again, commencing at the level of the lavas left in the conduit by the discharge; which rising continues until the augmenting forces, from one source or another, are sufficient for another outbreak.

In 1832 the conditions were ready for a discharge when the lavas had risen until they were within 700 or 800 feet of the top; in 1840, when within 650 feet; in 1868, when within 500 or 600; in 1886, when within 350 feet. The greater height of recent time may seem to show that the mountain has become stronger, or better able to resist the augmenting forces. But it also may show a less amount of force at work. In 1823, 1832 and 1840, the down-plunge affected a large part of the whole floor of the crater, which proves not only the vastness of the discharges, but also indicates active lava through as large a part of the whole area preceding the discharge, while in 1886, the down-plunge and the active fires in view were confined to Halema'uma'u and its vicinity. It was not in earlier time, therefore, the greater weakness of the mountain, but probably the greater power of the volcanic forces.

The broad low-angled cone which the volcano tends to make, has a great breadth of stratified lavas to withstand rupturing forces. How great may easily be calculated by comparing a

cone of 8° or 10° with one of 30°, the latter the average angle of the greater volcanic mountains of western America; and this suggests important differences in the results of volcanic action independent of those consequent on the possible prevalence of cinder-ejections in the latter. But somehow or other Mauna Loa breaks easily—very easily, its quiet methods say—and it seems to be because such rocks, however thick, can offer but feeble resistance to rupturing volcanic agencies.

In the discussion beyond of the operations going on and of their causes, I speak, I, of Kilauea as a Basalt-volcano, the basis of its peculiarities; II, of the size of the Kilauea conduit; III, of the ordinary work of the volcano; IV, of its eruptions; and V, of the contrast in volcanic action between Kilauea and volcanos of the Vesuvian type.

I. KILAUEA A BASALT–VOLCANO.

1. *The mobility of the lavas.*—The phenomena of Kilauea are largely due to the fact that it is a basalt-volcano in its normal state. By this I mean, first, that the rock-material is dolerуte or basalt, and secondly, that the heat is sufficient for the perfect mobility of the lavas, and therefore for the fullest and freest action of such a volcano. It is essentially perfect mobility although there is not the fusion of all of its minor ingredients, that is of its chrysolite and magnetite. This is manifested by the lavas, whether they are in ebullition over the Great Lake, throwing up jets 20 to 30 feet high, throughout an area of a million square feet or more, or when only splashing about the liquid rock and dashing up spray of little lava drops from areas of a few square yards. There is in both conditions the same free movement, almost like that of water, and suggesting to the observer no thought of viscidity. Of the two conditions just mentioned, the former was that of November, 1840, the latter that of August, 1887; and that of August seemed to be the more wonderful, because we naturally look for some of the stiffening of incipient solidification where only a few square yards of lava are in sight.

2. *This mobility is dependent largely on the fusibility of the chief constituent minerals of the lava.*—Along with augite, a relatively fusible species, the rock contains, as its other chief constituent, labradorite, almost as fusible as augite, and the most fusible of the feldspars. Andesine and oligoclase are less fusible feldspars, and orthoclase is of difficult fusibility. Thus in this prominent physical character the feldspars widely differ, and accordingly there should be, and are, volcanoes of different characteristics, for example, Andesyte volcanoes, in which oligoclase or andesine is the pre-

dominant feldspar, and Trachyte and Rhyolyte volcanoes in which orthoclase is a chief constituent; and, besides these, there are also intermediate grades or kinds.

The differences in form and action among these kinds of volcanoes depend chiefly on the physical quality of *fusibility*, but partly on that of *specific gravity*.

Neither of these qualities, it is to be noted, has any relation to the *acidic* or *basic* character of the feldspar or rock, that is to the amount of silica present. The distinction of *basic* and *acidic*, of great interest mineralogically and chemically, has in fact little importance in the science of volcanoes, while that of fusibility is fundamental. The most basic of all the feldspars, anorthite, is as little fusible as the most "acidic" of feldspars, orthoclase, and more so than the equally "acidic" albite.* It is plain therefore that the quality of being *basic*, does not explain the fusibility of the lavas. Neither does it explain any other of the physical characteristics on which the peculiarities of the volcano depend.

It is also true that the chrysolite (or olivine), the ultra-basic constituent of the lavas, has little influence on their physical characters except through its high specific gravity—which is about 3·3 to 3·4. The mineral chrysolite is infusible, and cannot *increase* the mobility of the lavas; and there is commonly not enough of it in the Kilauea rocks to diminish the mobility; for a large part of the lava contains less than 5 per cent, and much of it less than ·1 per cent. Chrysolite, is *ultra-basic;* but this quality has little volcanic importance. It is not the little amount of silica in it that is influential volcanically but the much iron, the ingredient that gives it its high density or specific gravity. The presence of much chrysolite may affect the distribution of the lavas in the conduit, or of the out-flows from the conduit, on account of their high density; but it does not accomplish this through the ultra-basicity of chrysolite, but through its ultra-ferriferous character, and the conditions under which it is formed.

3. *The degree of mobility is dependent also on temperature.* —It is probable, that at the temperature of fusion, or better a little above it, all the feldspars, the least and the most fusible, are nearly alike in mobility. But the lower the degree of fusibility the less likely is the heat to be deficient, or below that required for complete fusion and mobility; and here comes in the great difference among them as regards lavas and volcanoes.

The basalt-volcano has special advantage over all others in this respect, as the copious Mount Loa lava-streams and the

* In my Manual of Mineralogy and Petrography, page 436, I point out further that the distinction of alkali-bearing and not alkali-bearing among the silicates is of much more geological importance than the much used one of acidic and basic.

immense basaltic outflows of other regions exemplify. In Hawaii the heat required for the existing mobility is no greater than the deep-seated conditions below the mountain can keep supplied, in spite of cooling agencies from the cold rocks, the subterranean waters and the air; it is no greater than it can continue to supply for half a century and more, as the records have shown; and supply freely to the top of a conduit 3000 to 3500 feet above the sea-level, and even to the top of another conduit but twenty miles off, rising to a height of 13,000 feet above the sea-level. The temperature needed for this mobility judging from published facts, is between 2000° F. and 2500° F. The fusing temperature of augite and labradorite has not yet been determined. We are certain that a white heat exists in the lava within a few inches of the surface; for the play of jets in a lava-lake makes a dazzling network of white lightning-like lines over the surface; and white heat is equivalent to about 2400° F. Considering the height of Mt. Loa and the greatness of its eruptions, and the vastness of basaltic outflows over the globe, we may reasonably assume that the temperature needed for the normal basalt-volcano has long been, and is now, easy of supply by the earth for almost any volcanic region; and that the difficulty the earth has in supplying the higher heat for equal mobility in a trachyte or rhyolyte volcano is the occasion of the common semi-lapidified pasty condition of their outflowing lavas.

Even if the higher temperature required for orthoclase-lavas, were always present quite to the surface in the volcano, the ordinary cooling influences of cold rocks and subterranean waters and air would be sure to bring out, in some degree, on a globe with existing climatal conditions, the characteristics of the several kinds of volcanoes designated.

I do not say that this higher heat required for the complete fusion of trachyte or rhyolyte is wanting at convenient depths below; for it has been manifested in the outpouring of vast floods of these rocks through opened fissures, many examples of which over the Great Basin are mentioned in King's "Systematic Geology" of the 40th Parallel. But in the volcano, whose work, after an initial outflow, is carried forward by periodical ejections and requires for long periods a continued supply of great heat, the more or less granulated or pasty condition of the outflowing orthoclase-bearing lava streams is the usual one. Consequently, when a volcano changes its lavas from the less fusible to the more fusible, as sometimes has happened, some change in the features of the volcano should be looked for, except perhaps when the change occurs directly after the initial discharge.

Here the question suggests itself whether the temperature existing at depths below may not be one of the conditions that determine whether the discharged lavas shall be of the less fusible or the more fusible kind.

But a *basalt*-volcano also may fail to have heat enough for perfect fusion, and hence have partially lapidified or pasty lavas, and thus be made to exhibit some of the characteristics of the other kinds of volcanoes. This condition may result from three causes: (1) A decline in the supply of heat of the conduit, as when the partial or complete extinction of the volcano is approaching; (2) When the lava is discharged by lateral openings or fissures, in which case the lateral duct of lava may not be large enough to resist completely the cooling agencies about it; (3) The sudden entrance of a large body of water into the conduit.

The effects from the *first* of these conditions—declining heat connected with approaching extinction—are strikingly exemplified in two great volcanic mountains of the Hawaiian Islands, Mt. Kea on Hawaii, and Haleakala on Maui. Those of the *second*, in which the ejections are from lateral openings, are abundantly illustrated in the cinder and tufa cones of the islands, and also in widespread cinder or ash deposits through the drifting of the ejected material by the winds. The *third*, a sudden incursion of waters through an opened fissure, if a possibility, should both lower the temperature and produce violent projectile results, and even Kilauea bears evidence of at least one eruption of great magnitude which was thus catastrophically produced; for the region bordering the crater on all its sides, and to a distance of ten or fifteen miles to the southwest, is covered with the ejected stones or bowlders, scoria and ashes of such an eruption.

4. *Eruptive characteristics of a Basalt-volcano.*—The obvious results of superior mobility and density in lavas, are, as in other liquids:

(1) First: greater velocity on like slopes, and thus an easier flow, with less liability to be impeded by obstructions; a lower minimum angle of flow, and consequently a less angle of slope for the lava cones.

(2) Secondly: The vapors ascending through the liquid lava encounter comparatively feeble resistance, and hence the expansive force required for escape of bubbles through the lava to the surface is feeble; and so also are the projectile effects due to the explosion of the bubbles. Hence the projected masses commonly go to a small height—it may be but a few yards—and fall back before cooling, instead of reaching to a height that involves their cooling and solidification in the fall and the making thus of cooled fragments of lava or scoria, called cinders and volcanic ashes.

The projectile process in the basalt-volcano, as long as it is in its normal stage, makes not cinder-cones, but *dribblet-cones*, 15 to 40 feet high, out of the projected masses, the falling driblets becoming plastered together about the smaller places of ejection. Such cones consist of cohering drops, clots, pancake-like patches, or abortive streamlets, and form into spires and columns on rude bases and take other fantastic shapes. They are necessarily small, and mostly of blow-hole origin, because when the vent is broad, like a lava-lake, the jettings fall back into it again; yet enough may fall on the margin of a lava-lake to gradually raise and steepen its border. Such driblet-cones are of all angles from 30° to 90°. Among the projectile results of volcanoes, driblet-cones are at one extremity of a series, and cinder or tufa cones, many hundreds of feet high, at the other. A cinder cone of 1000 feet in height has 15,000 to 20,000 times the bulk of any driblet-cone. The process is one; but the result varies with the mobility and fusibility of the lavas.

Further: in the great lava cone of a basalt-volcano in its normal stage, cinder or tufa deposits rarely alternate with the large lava-streams, while they commonly alternate in other kinds of volcanoes.

Further: cinder cones and beds of volcanic ashes may form about a basalt-vocano, as already explained, whenever the condition of insufficient heat is in any way occasioned.

The above views as to the characteristics of a normal basalt-volcano are sustained by the facts from the volcanic mountains of all the Hawaiian Islands.

In the first place, the slopes are not only the lowest possible, usually from 1° to 10°, but continuous flows of 10° to 90° occur. I have seen many of them descending as unbroken streams vertical precipices on southern and western Hawaii.

Again the alternation of the lava-streams of the great volcanoes with deposits of volcanic sand, scoria or stones that were ejected from the great craters, is of rare occurrence, and such deposits make only thin beds of the kind whenever they occur. In such examinations as I have been able to make of the walls of Kilauea and Haleakala, and of the precipices and bluffs of Oahu, I have not succeeded in finding cinder or tufa deposits among the layers. The walls of Kilauea are stratified from top to bottom, but with lava-streams, and comparatively thin streams; I could find no evidence, in my examination of its walls, of any intervening stratum or bed of scoria, tufa or stones like that which now covers its border. This testimony is not conclusive as to the absence of such projectile eruptions in former times, for thin beds of scoria or sand like that just referred to—its thickness is only 25 to 30 feet—might be fused

and annexed to the succeeding lava-flow. But the evidence against *great* tufa deposits, excepting those from lateral ejections, is, I believe, sufficient; and by great I mean 50 or 100 feet; not the 1000 feet and more common in the regions of the Rocky Mountains and the Pacific border.

On the island of Maui, I found no such beds of projectile origin in the walls of Haleakala, or in those of Wailuku valley the probable crater cavity of western Maui. On Oahu, the pitch of the layers of lava along the Manoa and Nuuanu valleys is only 1° to 3°; and in the precipices and bluffs which bound them I saw no layer of tufa. The thick tufa deposits are confined to cinder and tufa cones, and these are common.*

This point needs investigation; for the existence of even thin tufa beds in alternation with the lava beds of the great volcanoes of the islands, may still be true, and such facts would have much interest.

5. *The crater of a basalt-volcano is the same in origin, history and functions as those of volcanoes of other kinds, but differs usually in form.*—The crater of a great volcano probably has always its beginning—as I set forth in my Exploring Expedition report—in a great discharging fissure. But once open, it usually continues open until a temporary or final decline of volcanic action, whatever the kind of volcano. It continues open because (1) of the fixed position of the supply conduit; because *secondly* of the conduit-work going on through it in the discharge of vapors and lavas; and because, *thirdly*, of the down-plunges in the crater consequent on the undermining which the discharge of the conduit occasions. The open end of a deep-reaching conduct determines thus, by its discharges and the subsequent underminings, the existence of the crater; and the crater, by the work done within and about it, makes the volcanic cone. This appears to be the order of rank or importance in the phenomena—the crater begins in the opened fissure and is the indicator and future builder of the cone. In the history of the volcano, the era of summit outflows may pass, and only lateral discharges take place; and still the discharge of vapors from the lava conduit and the accompanying movements in the lavas, together with the down-plunges in the crater following the discharges, will keep the crater, or portions of it, in continued existence, and the work of eruption or outflow, if subaerial, is still adding to and shaping the cone.

This is the present stage of Kilauea and Mt. Loa; and these are the results as they exemplify them. The action, functions

* The cinder or tufa deposits of lateral cones have often great extent. This is well seen on Oahu, where Diamond Hill, Punchbowl, and the region about Aliapaakai or the Salt Lake, are examples.

and processes are the same whether the lavas fill up to the summit before outflowing, or become discharged at a lower level by an opened fissure.

Examples in the Hawaiian Islands teach also that volcanoes may end with an open crater over 2,000 feet deep, like Haleakala, a cone 10,000 feet high, or with a filled crater, as in the case of Mt. Kea, 13,800 feet high.

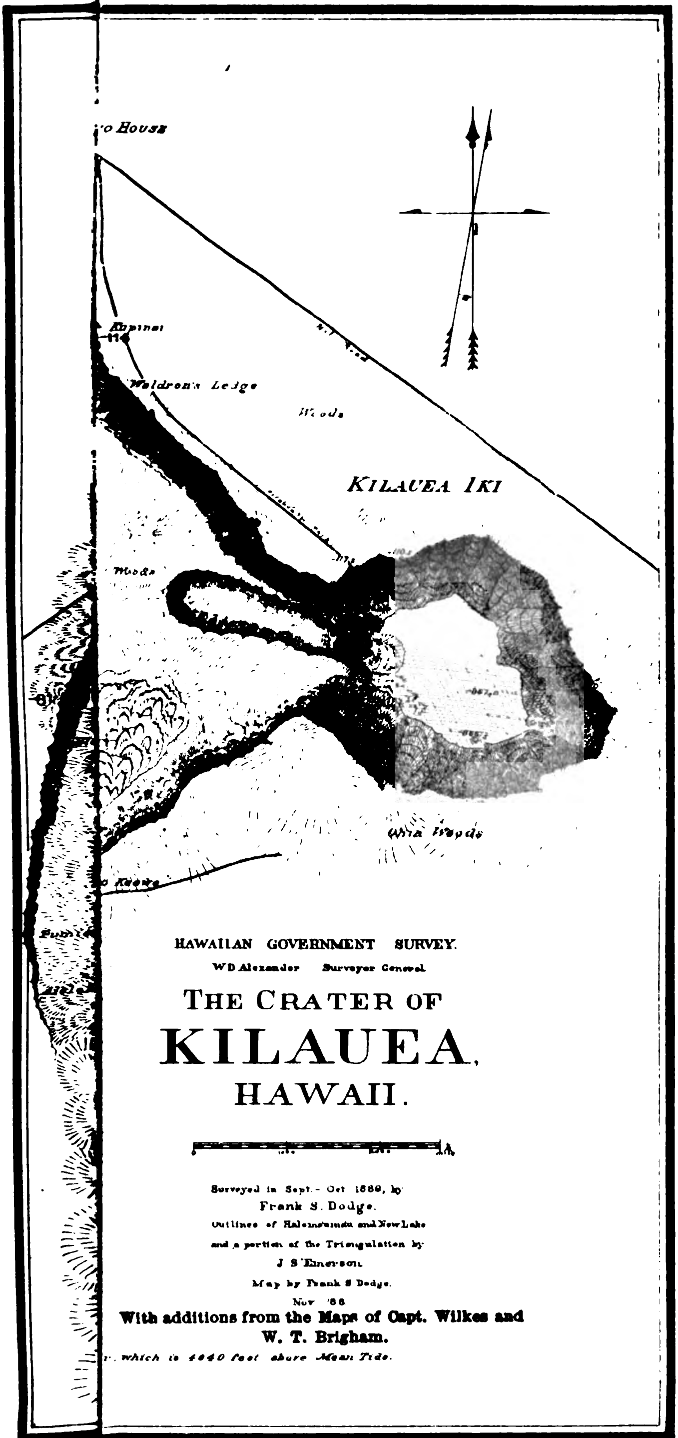
The preceding remarks about the permanence of craters apply to other kinds of volcanoes as well as the basaltic; but in the form of the crater the basalt volcano has peculiarities, owing to the mobility of the lavas and the paucity of cinder discharges. The ordinary crater of such volcanoes is pit-like, with the walls often nearly vertical, and the floor may be a great, nearly level plain of solid lavas. The liquid material of the extremity of a conduit works outward from the hotter center, through the fusing heat and the boiling and other cauldron-like movements; and hence, where the mobility favors freedom of action in these respects, it tends to give the basin or crater a nearly circular form with steep sides—an explanation I give in my Expedition report. Besides, when the discharge takes place there is usually a fall of the walls which is still another reason for vertical sides, and the pit-like form.

The small lava-lakes of Kilauea, and the Great South Lake also after a discharge, (or an eruption as it is usually called) are literally pit-craters. Such was the condition of the Great Lake after the eruption of 1886. They all illustrate how the great pit-crater, Kilauea, was made. The lower pits of 1823, 1833, 1840 are other examples.

Such pit-craters are normally circular; but where there is a large fissure beneath the crater, they may be much elongated.

From the considerations which have been presented we see why the volcanic mountains of the Hawaiian Islands, with slopes rarely exceeding 10° in angle, differ so widely from the great andesyte cones of western North America, with their high slopes of 28 to 35 degrees. We see that the fact of being basalt-made means much in a volcano; that it affects profoundly all the movements and the results of those movements as well as the shapes of the mountains and of their craters.

[To be continued.]


o House
Waldron's Ledge
Woods
KILAUEA IKI
Woods
HAWAIIAN GOVERNMENT SURVEY.
W D Alexander Surveyor General
THE CRATER OF
KILAUEA,
HAWAII.
Surveyed in Sept.-Oct 1886, by
Frank S. Dodge.
Outlines of Halemaumau and New Lake
and a portion of the Triangulation by
J S Emerson
Map by Frank S Dodge.
Nov '86
With additions from the Maps of Capt. Wilkes and
W. T. Brigham.
which is 4040 feet above Mean Tide.

[From the American Journal of Science, Vol. XXXV, March, 1888.]

Art. XIX.—*History of the Changes in the Mt. Loa Craters;* by James D. Dana. Part I. Kilauea. Continuation of the Summary and Conclusions.

[Continued from xxxiii, 433; xxxiv, 81, 349; xxxv, 15 (Jan., 1888).]

II. SIZE OF THE KILAUEA CONDUIT.

To appreciate the power at work in Kilauea and understand its action we should know, if possible, the diameter of the lava-conduit; and for this we have to look to its condition both in times of eruption and in periods of relative quiet.

In view of the greatness of the discharge in 1823—so undermining, owing to its extent, as to drop abruptly to a depth of some hundreds of feet the floor of the crater, leaving only a narrow shelf along the sides—we reasonably conclude that, at that time, the conduit beneath was of as large area as the Kilauea pit itself—or nearly seven and a half miles in circuit. We may also infer that, immediately before the discharge, wherever there was a lava-lake, the liquid top of the conduit was up to the floor of the crater, and elsewhere not very far below it. The inference is similar from the eruptions of 1832 and 1840. When the floor of the pit fell at the discharge in 1840, it was not thrown into hills and ridges, as it might have been had it dropped down its 400 feet to solid rock in consequence of a *lateral* discharge of the lavas beneath; on the

contrary, it kept its flat surface, thus showing that it probably followed down a liquid mass, that of the subsiding conduit lavas.

But it is probable that the conduit had then, and has still, a larger area than that of Kilauea

At the eruption of March, 1886, when the emptying of Halema'uma'u and its bordering lake, at the south end of Kilauea, was all the visible evidence of discharge, the Solfatara at the north end, two and a half miles from Halema'uma'u, showed sympathy with the movement. For the escape of vapors from its fissures suddenly ceased, as if the *source* of the hot vapors had participated in the ebb, while a few hours before the discharge the vapors were unusually hot, so as to prevent the use of the bath-house (xxxiv, 351). Thus, even now, during a comparatively small discharge, we have evidence that the two distant extremities of the crater are underlaid by inter-communicating liquid lava. Mr. Brigham speaks of hearing, in 1880 (xxxiv, 27) when at the vapor-bath house in the Solfatara, sounds from below, "rumbling and hard noises totally unlike the soft hissing or sputtering of steam," a fact that seems to favor the above conclusion. Further, through all known time, as now, several of the fissures in the Solfatara region have discharged, besides steam, sulphurous acid freely, and this can come only from liquid lavas.

The summit of the conduit must, therefore, be even larger than all Kilauea. To this may perhaps be added the bordering region of fissures and abrupt subsidences; for subsidences or down-plunges indicate undermining, and undermining here means the removal of liquid material from beneath. With this addition to the limits, the width is 16,000 feet and the length as much, *plus* a mile or more to the southwest, where the fissures of 1868 if not also of earlier date, are giving off hot vapors abundantly.

But while this may be the area of the upper extremity of the conduit, the top surface is not a level plane, as the condition of the region above it indicates. A small part of it at all times (with short exceptions after an eruption) has extended up to the surface in Halema'uma'u, and occasionally in other lava-lakes during times of special activity; for each such lake, however small, must have its separate conduit reaching down to the general liquid mass and giving upward passage to the working vapors. We learn hence that whatever the number of these conduits, they may act independently, that is overflow, and rise and fall in level, because the size is very small compared with that of the reservoir from which they rise.

III. THE ORDINARY WORK OF KILAUEA.

By the ordinary work of Kilauea is here meant the work which is carried on between epochs of eruption. A large part of it is the living work of the volcano, the regular daily action, never permanently ceasing except with the decline and extinction or withdrawal of the fires. The deep-reaching conduit of lavas, which is the source of the heat and center of this living activity, owes a large part of its power to act the volcano, and make a volcanic mountain, to the presence of something besides heat and rocks. Vapors are ever rising and escaping from the conduit, and though lazy in the clouds above where the work is done, they carry on nearly all the *ordinary* action of a crater, even that of greatest brilliancy and loftiest fiery projection as well as the gentler play of the fires. But these vapors have not produced the great eruptions in Kilauea since 1822; they occasion only its quiet or lively activity in periods of regular work between eruptions. I add also, lest I be misunderstood, that the vapors are bad for fuel, as they tend to put the fires out, but good for work.

There is another source of work, perhaps a perpetual source during the active life of a volcano as it is a perpetual source of heat, namely, the ascensive force of the conduit lavas. But, unlike the vapors, it is an invisible agency, slow in its irresistible movements. What are its limitations, and what its source still remain undetermined.

The other agencies concerned in the ordinary work have only occasional effects. They include heat in work outside of the conduit, and hydrostatic and other working methods of gravitational pressure.*

Tabulating the agencies, they are as follows:

A. The vapors.
B. The ascensive force of the conduit lavas.
C. Heat, displacing, disrupting, fusing.
D. Hydrostatic, and other gravitational pressure.

All these agencies do their work around the lava conduit, or its branches, as their central source of energy. Unlike non-vol-

* The following account of Kilauea in December, 1874, was omitted from page 94 of vol. xxxiv. It is from a brief note by Mr. J. W. Nichols, of the British Transit of Venus Expedition of 1874. published in the Proceedings of the Edinburgh Royal Society for 1875–6, pp. 113–17. A low cone around Hale-ma'uma'u about 70 feet high; diameters of the basin ⅓ m. and ¼ m.; within it, four lava lakes, the largest 200 yds. in length; in the largest, 7 to 8 fountains of white-hot lava playing to a height of 30 to 40 feet, one of them sometimes stopping, and then commencing in another part of the lake; the fountains in every case playing around the edges of the lake; lava of largest lake about 50 feet below the brim; one of the smaller lakes brim full of lava when in the others the lava surface was 30 or 40 feet below the brim; in one, a single fountain bursting from a cavern in its side. The summit crater is stated to have been in action about a month before the visit.

canic igneous eruptions and nearly all other geological operations, the results are *pericentric*. Overflows and outflows, aerial discharges and their depositions, fissure-making, subsidences, elevations, everywhere illustrate this fundamental principle in volcanic action. As the volcanic mountain with its crater is its emphatic expression, so is almost every little heap of lavas, or cinders, that may form within the crater or over the mountain slopes.

A. *The work done by vapors.*

Only part of the work of vapors is of the permanent kind, carried on, as above described, by the vapors rising *through* the lavas of the conduit. Another efficient part, but most efficient in times of eruption, is dependent on vapors generated *outside* of the conduit. In addition, there are the chemical effects of vapors. The work includes:

(1) The effects of the expansive force of vapors in their escape from the liquid lavas: projectile action and its results.

(2) The effects of the expansive force of vapors within the liquid lavas: vesiculation and its results.

(3) The effects of vapors generated outside of the conduit: fractures, displacements, etc.

(4) The chemical action of vapors; which is considered only as regards certain metamorphic effects, in connection with the account of the Summit crater.

1. THE VAPORS CONCERNED: THEIR KINDS AND SOURCES.

The vapors of Kilauea have not yet been made a subject of special investigation. Still, there is no question that the chief *working* vapor is the vapor of water; besides which there is a little sulphur gas, and probably some atmospheric air. Investigations elsewhere have shown the vast predominance of water-vapor among aerial volcanic products proving that less than 1 part in 100 is vapor of any other kind. The statement of Mr. J. S. Emerson (xxxiii, 90) that on the west margin of Halema'uma'u, at one of his surveying stations in April of 1886, to leeward of a "smoke-jet," he continued his work "without regard to the smoke which the wind carried over him within a few feet of his head," is proof that the air held little sulphurous acid. Great volumes of vapors were constantly rising from Halema'uma'u in August, 1887.

Mr. Brigham was led to conclude from his seeing so little vapor rising from the Great Lake during his visit, that too much influence had been ascribed by others to water;* and this view is presented also by Mr. W. L. Green, of Honolulu,

* Brigham, Memoir, p. 450, and this Journal, xxxiv, 24.

who refers part of the movements in the lake to escaping atmospheric air; the air being supposed to be carried down by the splashing and jetting lavas, there to become the source of the splashing; and to become confined in this and other ways, and be carried deeper for other work.* But the amount of vapor escaping from a lake in times of moderate activity, when it is mostly crusted over, is very small—being only that from the vesicles (p. 194) and breaking bubbles in the actively liquid portion; and in a state of brilliant action, the hot air above, up to a height where the temperature is diminished from that of the liquid lavas to 300° F. will dissolve and hold invisible nearly 5 times as much moisture as at 212°; up to 440°, 16 times as much; and to 446°, 27 times. The absence of vapors over a flowing lava stream is made evidence against the presence of water; but if all is from one source, *there should be none* except at the source (ibid.)

The amount of sulphur in the vapors, and its condition before the escape from the lava, whether as sulphur vapor simply or as sulphurous acid (sulphur dioxide), are questions for the future investigator. Pyrite, or some iron sulphide, being its probable source, I add that I have detected pyrite in the lava of a dike on Oahu, but not in the lavas of the crater, where we should hardly expect its presence. Chalcopyrite (copper pyrites) may also be present; for, in 1840, I found, at the southwestern sulphur banks, some blue copper sulphate.† The faintly greenish tint of the flames which have been seen (xxxiv, 24, 356) may have this source.

Carbonic acid has not been observed escaping from fumaroles about any part of the Hawaiian Islands, and no fragments of limestone have been found among the ejectamenta of Kilauea or Mt. Loa The volcanoes stand in the deep ocean, and the conduit must come up through old lavas for thousands of feet, and hence carbonic acid is only a possible not a probable product. The position of the volcanic region in mid-ocean, where continental geological work has, most probably, never gone forward, makes it questionable whether limestone is passed through by the hot lavas at any depth.

The presence of *hydrogen* among the escaping vapors remains to be determined. The pale, hardly bluish flames seen about the Great Lake may come from the burning of escaping hydrogen, or of sulphur vapor, or of hydrogen sulphide.

The *source of the water or moisture*, whence comes the chief part of the escaping vapors, is probably atmospheric. On this point the arguments appear to be as strong now as in 1840.

* Vestiges of the Molten Globe, Part II, 8vo, Honolulu, 1887.

† My Exped. Report, pp. 180, 201, 202, the last containing an analysis.

Kilauea is situated, like Hilo, in a region of almost daily mists or rains, and if approaching Hilo in the precipitation, as is probable, over 100 inches of rain fall a year. Tables give over 200 inches some years for Hilo. The whole becomes subterranean except what is lost by evaporation; for, owing to the cavernous and fissured rocks, there are no running streams over the eastern or southeastern slopes of the island south of the Wailuku river which comes down from the northwest to Hilo. That which falls into the crater and on its borders gives moisture to the many steaming fissures; and sometimes it makes a steaming area of the whole. But this part has very little to do with the volcanic action.

A part of the subterranean waters follow the underground slopes seaward, as shown by copious springs in some places near the shores; and these also take no part ordinarily in the volcanic work. But another part must descend by gravity vertically, or nearly so, and keep on the descent far below the sea level. It has been shown on a former page (p. 16) that much the larger part of the eruptions have occurred in the months from March to June, and this appears to indicate a dependence of the action to some extent, on the abundance of precipitation.*

Moisture may be gathered also from all moist rocks along the course of the conduit in the depths miles below the reach of superficial waters, as suggested by different writers on volcanoes. But any dependence on the amount of precipitation would show that this is not its chief source.

Another source of water is the sea. But sea-water could not ordinarily gain access to the conduit except at depths much below the sea-level, on account of the abundance of subterranean island waters pressing downward and outward. Further, no one has yet reported evidence of the presence of marine salts, or chlorides, beyond mere traces, among the saline products of Kilauea or Mount Loa after an eruption.

A third source of moisture is the deep-seated region in or beneath the crust whence the lavas come. Of this we know nothing. The fact that the presence of such moisture below would make this a dangerous earth to live on has been urged against the idea of such a source.

Since all ordinary action in Kilauea, and also in Mt. Loa, is of the quiet non-seismic kind, the introduction of water into the conduit must be an ordinary and a quiet process, not one of sudden intrusion through fissures. Sudden intrusions may

*This view with regard to the sources of the waters is sustained by several writers. It is well presented, with explanations at length as to the water line in the volcanic mountains, in a paper on "the Agency of Water in Volcanic Eruptions," by Prof. Joseph Prestwich, Proc. Roy. Soc., xli, 117.

sometimes take place for eruptive effects, but of these we are not speaking. The facts from the vesiculation of some lava-flows of Mt. Loa brought out beyond (page 195) give further evidence as to the quiet molecular occlusion of the waters. Moreover, the possibility of this method of imbibition appears to be demonstrated by Daubrée's experimental work, which proves that the process will go on through capillarity or molecular movement, against the opposing pressure of vapors within.* He uses the fact to explain the origin of volcanic vapors.

The water seeking entrance in the depths below, moreover, is under pressure from above, and, whatever the temperature, the forcing of it back against this pressure and friction is impossible; the expansive force generated by the heat only forces it into the rising lava of the conduit, as urged by Mallet, and sustained by Prof. Prestwich.

I proceed now with the consideration of

2. THE EFFECT OF THE EXPANSIVE FORCE OF VAPORS IN THEIR ESCAPE FROM THE LIQUID LAVAS: PROJECTILE ACTION.

All the lava-lakes of the crater, whether one alone exists or many, and the smaller vents over fires that are concealed but not at too great depths, send forth vapors, which, in their effort to escape as bubbles through a resisting medium, that is, the lavas, do projectile work. The vapors thus produce the play of jets over lava lakes with the muffled sounds and tremor of ebullition; and also the splashing and the throwing of spray from open fire-places in the crusted lakes. They dash up the melted fragments from a blow-hole with a rush and roar "rivalling sometimes a thousand engines," thus introducing the coarser effects of gunnery into Kilauea. They make the thin crust of the crusted lake to heave and break, press into rope-like folds the lava along the red fissures, or start a new play of fiery jets, high or low, and frequently several in alternate play; or, they make openings and push out a flood of lava; and occasionally, when rising in unwonted volume, they make lava-fountains of unusual heights over the lakes, with at times loud detonations.

The projectile force required to throw up jets of lava to the ordinary height they have in times of brilliant activity, thirty feet or so (see pages 31, 32), is even less than a calculation from the height, diameter and density would make it, because the

* Géologie Expérimentale, 2 vols., 8vo, Paris, 1879, p. 235.

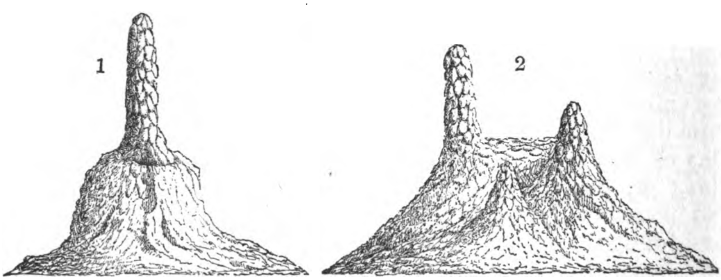
The temperature of the liquid lava is nearly that of the dissociation temperature of water—1985° F. to 2370° F. according to M. H. St. Claire Deville,—and higher than this no doubt at depths below. But that dissociation takes place within the conduit, under the pressure there existing, is not satisfactorily proved.

jets before they reach their limit usually have become divided into clots, instead of remaining a continuous stream.

The fact that the throw in the projectile action of a crater is usually vertical is well shown in some of the columnar driblet-cones. This is the case in that of fig. 1 below, in which the column was elongated vertically, although a result of successively descending drops. In the figure referred to, the place of ejection was at the base of the vertical part, and it is probable that the force which determined the slight obliquity in the throw required for so uniform a fall on one side of it, was that of the prevailing wind. This vertical throw,—due to the fact that the top of the bubble is the weak, and, therefore the exploding spot—makes the projectile action good for throwing up, but not good for a destructive bombardment of a crater's walls.

Common observations would lead us to expect that in a low state of the fires, when the large lake is for the most part thinly crusted over, the point of greatest heat and action would be toward the center; instead of this it is usually at the margin, and often in oven-like places partly under the cover of the border rocks. The only explanation that now appears is this: that along the border, the outside cold, or that of the atmosphere, is much less felt than over the central portion.

One of the *secondary results*, over the floor of the crater, of the projectile work is the making of the fantastic *driblet cones*, formed often about blow-holes out of the descending clots and drops, as already explained. The forms of two of these cones are shown in the following figures: the first from my



Driblet Cones.

Expedition Geological Report (page 177) representing a fountain-like structure about forty feet high made of lava-drops; the other from Mr. Brigham's Memoir (page 423), representing "the Cathedral" as seen by him in 1864, and also earlier and later by Mr. Coan (xxxiv, 88).

Occasionally the particles of the projected lava are small and descend in small showers of loose smooth-faced but variously

shaped bullets and granules around the vent; and this is the nearest the crater at present comes toward producing cinder-cones.

Besides making driblet-cones, the projectile work raises somewhat the borders of the lakes. Further, the small overflows, lapping in succession over the borders, often make them steep, and keep increasing their height until a heavier out-flow sweeps one side or another away.

A third incidental result of the projectile action is the making of *capillary glass*, or *Pele's hair*, from the glassy part of the lavas. In the jetting and splashing of the lavas, the flying clots and drops pull out the glass into hairs, just as takes place in the drawing apart of a glass rod when it is melted at middle. This is the explanation of Mr. Coan and others who have observed the action. Mr. Brigham says that "the drops of lava, thrown up, draw after them the glass thread, or sometimes two drops spin out a thread a yard long between them." His new observations of 1880 (xxxiv, 22) accord with this explanation but are remarkable for the length and size of Pele's tresses that he reports as hanging from the roofs of the fiery recesses. In my visit in 1840 to one of the smaller boiling lakes, I saw the rising and falling jets, and the work of the winds in drifting the spun glass; but my conclusion erred in attributing the spinning also to the winds.

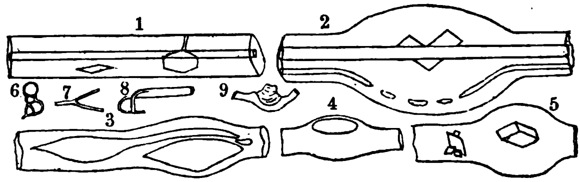
Captain Dutton's observations led him to another explanation, as follows:* "The phenomenon of Pele's hair has generally been explained as the result of the action of the wind upon minute threads of lava drawn out by the spurting up of boiling lava. Nothing of the sort was seen here, and yet Pele's hair was seen forming in great abundance. Whenever the surface of the liquid lava was exposed during the break up the air above the lake was filled with these cobwebs, but there was no spurting or apparent boiling on the exposed surface." He then speaks of the vesicles made by the energetic escape of water-vapors, as solidification at the surface commences, and of their "walls as capable of being drawn out into threads as in the case of glass." The descending of the pieces of cooled crust "produces eddies and numberless currents in the surface of the lava;" and as a consequence "the vesicles are drawn out on the surface of the current with exceeding tenuity, producing myriads of minute filaments" and the air agitated by the heat "lifts and wafts them away." "It forms almost wholly at the time of a break-up; the air is then full of it."

The microscopic structure of the capillary glass has been studied with care by C. Fr. W. Krukenberg.† In his fifty

* Report, p. 108.

† Micrographie der Glasbasalte vom Hawaii; petrographische Untersuchung, 38 pp. 8vo, with 4 plates; Tübingen, 1877.

figures, a few of which are here copied, the glassy fibers are sometimes forked or branching; sometimes welded at crossings; often contain air-vesicles (3, 4), and microscopic crystals (1, 2, 5); often tubular (1, 2) through the drawing out of a minute



Pele's Hair. (Krukenberg.)

air-vesicle. They also show that the air-vesicles sometimes continued expanding as the glass was drawn out; and that the hair is often enlarged about enclosed crystals. The crystals are rhombic, as in the figures. The facts make it evident that the glass is far from being pure glass.

3. THE EFFECTS OF THE EXPANSIVE FORCE OF VAPORS WITHIN THE LAVAS: VESICULATION AND ITS MECHANICAL EFFECTS.

a. Origin.—Vesiculation, the making of bubble-like cavities in a melted rock, is a noiseless unseen effect of the vapors that are rising and expanding *within* the lavas. The expansion necessary to produce them is resisted by the cohesion in the lava, and by the pressure. Consequently it is a very common feature of the easily fusible volcanic rock, basalt, but not of trachyte or rhyolyte, except in pumice, the glassy scoria of these rocks; and even this glass (obsidian) commonly holds to its moisture, if it contains any, without vesiculating.

Owing to superincumbent pressure, the maximum depth of vesicles is small, as has long been recognized; but how small in basalt, or any other rock, has not been ascertained by experiment. It probably does not occur in the Hawaiian Islands below a depth of 200 feet. Above the lower limit, vesicles may increase in number and size toward the surface, and be largest in the scum or crust, as within Kilauea; but this variation upward is not always a fact.

b. Kinds.—Five styles of vesiculation may be distinguished in the Kilauea ejections, two of which characterize stony lavas, and three scorias.

(1) That of the ordinary lava-stream of the floor of the pit. The vesicles are oblong and of irregular shape, and constitute from less than 1 to 50 or 60 per cent of the mass of the rock. The form is spherical when the vesicles are very few and small.

(2) That of the common stony *spherically-vesiculated* lava. The vesicles make 30 to 60 per cent of the mass, and are too

small to be elongated much by the flow. This kind of lava occurs in streams outside of Kilauea, and in many about the slopes of Mt. Loa.

The best example of it I have seen, and the basis of the following description, is that of the 1880–'81 Mt. Loa flow, near Hilo. The small uniformly crowded vesicles constitute about 40 per cent of the mass. They characterize the lava, with scarcely any change in size and numbers, to a depth (as I found in a tunnel within the lava stream whose floor was similar) of 10 or 12 feet. Below this depth of 10 or 12 feet, the lava, as I learned from Rev. E. P. Baker of Hilo, is probably more solid, this being usually the case.

The scoriaceous kinds are:

(3) That of the glassy scoriaceous crust of the lava stream inside of Kilauea, and of the scum of its lava-lakes (xxxiv, 354). The vesicles are 65 to 75 per cent of the mass; they are elongated; those at top mostly closed; those of the bottom of the crust commonly very large. The crust of the lake is sometimes so thin that stones thrown on it slump through. The glass is easily fusible and hence its rapid fusion and cooling. An analysis of this scoria-crust made, at my request, by Professor O. D. Allen, proved it to have the composition of ordinary basalt.* No analysis has been made of the stony lava of Kilauea for comparison.

(4) Ordinary scoria, such as is common about cinder-cones outside of the crater, mostly stony in texture; the vesicles 65 to 95 per cent of the mass.

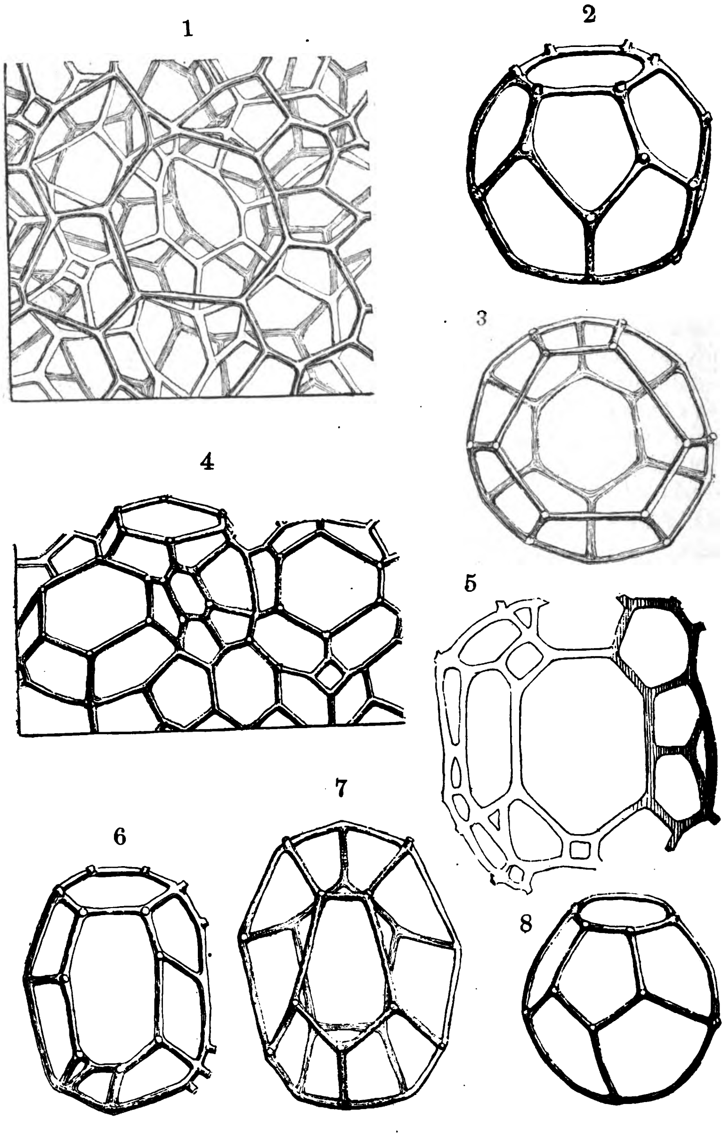
(5) Spongy, thread-lace glass scoria, occurring as a layer 12 to 16 inches thick over the southwestern border of Kilauea (xxxiv, 359); the vesicles 98 to 99 per cent of the mass; their walls in the coarser varieties sieve-like or reticulated; in the finer, like thread-lace in texture. Similar spongy scoria is reported as occurring at the summit of Mt. Loa and about the sources of some of the Mt. Loa lava-flows; but I have seen no specimens. Since a cubic inch of the finer thread-lace scoria contains only 1·7 per cent in bulk of rock material, a layer of solid

* Professor Allen's analysis (this Journal, III, xviii, 134, 1879) is in column A, below. For comparison, the composition is added of (B) the doleryte (diabase) of West Rock, New Haven, Conn., of Triassic age, by Mr. G. W. Hawes (Ibid., ix, 186, 1875), and of (C) a "typical" basalt from Buffalo Peak, east of the west fork of the Platte, between the two Parks, by R. W. Woodward (Geol. 40th Parallel, vol. ii, Descript. Geol., p. 126, 1877).

	SiO_2	Al_2O_3	Fe_2O_3	FeO	MnO	MgO	CaO	Na_2O	K_2O	ign.		P_2O_5	
A	50·75	16·54	2·10	7·88	*trace*	7·65	11·96	2·13	0·56	0·35		----	= 99·92
B	51·80	14·21	3·55	8·26	0·42	7·63	10·68	2·15	0·39	0·63		0·14	= 99·86
C	49·04	18·11	2·71	7·70	*trace*	4·72	7·11	4·22	2·11	1·29	TiO_2	2·46	= 99·47

I add that I do not cite here the analyses of the rocks and volcanic glass of Kilauea made by another for me and published in my Expedition Report, because they are erroneous and should be rejected.

basalt glass one inch thick would be sufficient to make a 60-inch layer of the spongy material; and probably a 75 to a 100-inch



Cells of the Thread-lace Scoria.

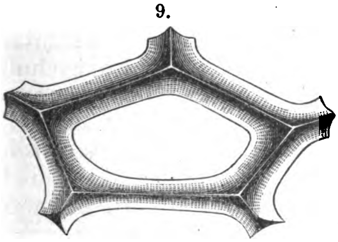
layer of the much more common, coarser variety, in which are some large vesicles occasionally half a cubic inch in size.

The vesicles of the finer kind are mostly $\frac{1}{30}$th to $\frac{1}{40}$th of an inch in diameter, like those of the 1880–'81 Mt. Loa flow; but their walls are reduced to threads corresponding to the edges of polygonal vesicles. Figure 1 shows the general appearance of the surface in a magnified view. The forms of the skeleton polygonal cells are, for the most part, either 12-sided or 14-sided figures, having a perimeter of ten or twelve pentagonal faces in two alternating rows, and bases of five or six sides. The 12-sided cells are bounded by the edges of pentagonal dodecahedrons such as come from the mutual pressure of spheres, except that they are distorted usually by compression, and by elongation or abbreviation. The 14-sided, which are much the most common, are similar to the 12-sided in general form, but have hexagonal bases. Fig. 2 is a side view and fig. 3 an end view of one of the latter kind, and fig. 4 shows a group of such cells, as seen over the surface of the scoria (a cut or broken surface, for it is impossible to handle a piece of the scoria without breaking off bits of the brittle threads). Fig. 6 is another of the 14-sided kind of less symmetrical form, as is common. One of the pentagonal dodecahedrons is shown in fig. 7, and another in fig. 8.

There is often a more complex system of network through other crossing contour-threads, but the simpler forms are referable to those represented. The inside of the base of one of the large and therefore less regular forms is shown in fig. 5, the diameter was about $\frac{1}{20}$th of an inch. In the largest vesicles the walls are openly reticulated.

The threads of this thread-lace scoria are not rounded, but parts of the contours of the three elliptical cells that were there in contact; and fig. 9 shows a portion of one. Having this form, the glassy material of the threads is thickest, and therefore of darkest color, at the center; and they are still thicker and darker at the angles or junctions of three threads.

9.



This glassy scoria calls to mind the vesiculation of an obsidian by a high heat, converting it into pumice or scoria because of its occluded water, as illustrated by Professor Judd, and also by Mr. Iddings in experiments with the obsidian of the Yellowstone Park. The Kilauea glass must have been penetrated molecularly with water to have produced such a result. Its ejection took place after the violent projection of great stones; and apparently not long after, as it overlies directly the layer of stones. The conditions of origin in the cases about the summit of Mt. Loa I cannot give. But the descrip-

tions seem to imply that the spongy scoria there is one of the results of high jettings or fountain-like throws of the lava during an eruption; it may be a light form of ordinary scoria.

The minute delicacy and brittleness of the threads in this scoria suggests a way of making fine dust by volcanic action, which is much more reasonable than that of mutual friction of projected fragments of scoria of the ordinary kind; it thus helps in the understanding of the lofty dust clouds of Krakatau and Tarawera.

c. Amount of moisture required for vesiculation, its distribution, and its origin.—The facts derived from the crowded vesiculated lava of 1880–1881, reaching from its source down to Hilo, over 30 miles, and throughout the whole range remarkable for uniformity and for depth in the stream, besides giving an opportunity to study the origin of the vesiculation and the amount of moisture it requires, presents also evidence as to the origin of the moisture in the conduit and its condition.

(1) As I learn from Rev. E. P. Baker, the vesicles change little toward the summit except in becoming coarser, with thinner walls, at the source. From the mean size, $\frac{1}{35}$ inch in diameter, we obtain for the *size of the particle of moisture* required at the ordinary pressure to fill one of the vesicles, ·000,000,007 of a cubic inch. What the size actually was, under the pressure and the temperature that existed at the time of vesiculation, cannot be determined. But this much we learn, that the moisture was distributed throughout the lava in a state of extreme division, actually or essentially that of molecular diffusion.

(2) The space in the vesicles is 40 per cent of the mass, as determined from the specific gravity of the rock-material, 2·98, and that of the mass with the surface varnished to exclude the water, 1·88. The required water is hence ·0003 per cent of the mass; or by weight ·0001 per cent; showing that, *the amount of water required for the vesiculation is exceedingly small.*

From the thread-lace scoria we find, since only 1·7 per cent of the mass is solid glass, that the amount of moisture required to produce the vesiculation, at the ordinary pressure, would be 3·125 per cent of bulk, and 1·1 per cent by weight The amount of moisture was hence not unusual for a rock, although the vesicles occupied 98·3 per cent of the mass.

(3) The source of the flow of 1880, 1881, according to Mr. Baker, was about 11,100 feet above the sea-level. This is 2575 feet below the summit of Mt. Loa, or about 1600 feet below the bottom of the summit crater. Before the outbreak, the liquid lavas were active within the crater; that is, the length of the conduit above the place of outbreak was then about 1800 feet. On account of the pressure of 1800 feet

of liquid lava no vesiculation could have taken place at this depth inside of the conduit; but at the discharge, the lavas escaped from the pressure, and the vesiculation by means of the diffused moisture must have then begun. Whether the vesiculation for the whole stream took place at or near the source cannot be decided without more knowledge of the flow and its actual sources than we now have. (See further on the Summit crater, in a future part of this paper.)

(4) The facts also tend to sustain the conclusion, before expressed, that the ingress of the subterranean waters, whatever their source, took place by molecular absorption; for it produced an essentially equable molecular distribution.

d. The distribution and functions of moisture after reception into the conduit.—(1.) The above conclusions from the vesiculation have prepared the way for additional deductions as to the distribution and movements of the moisture in the conduit. After its reception, it is exposed to a heat at least 1500° F. beyond the critical point of water (773° F.) and retains the temperature of fusion to the surface. If the expansive force has at the ingress under the pressure any effective value, the accession of the moisture will diminish somewhat the density of the lava, that is, increase its bulk; and this increase will be greatest along the central region of the conduit because this is the region of greatest heat. If dissociation takes place, the increase is still greater, as it adds to the bulk of the moisture. It is a question, therefore, whether the pressure of the denser *lateral* lavas of the conduit would not have some effect toward producing an upward movement along the hotter central region.

(2) The mechanism of the volcano, as regards these inside vapors, seems then to be this: (1) a molecular absorption, at depths below, of subterranean waters from regions either side; (2) a rise of the lavas, thus supplied with moisture, along the conduit from some cause (see beyond on "the ascensive force of the conduit lavas") and perhaps partly in consequence of the vapors present; (3) after reaching a level where the pressure is sufficiently diminished, a union of the molecules of water into gas-particles, *producing* by their expansive force *vesiculation;* (4) a further union of particles into bubbles, when the vapors are sufficiently abundant, in order to exert the greater expansive force required to escape through the surface of the lavas, *producing projectile results.*

e. Mechanical effects of vesiculation.—Vesiculation tends in a quiet way to increase bulk, as the above mentioned facts illustrate. It therefore will give increased height to the liquid lava in a conduit. How deep down this effect is appreciable is a point of much importance in its bearing on the movements

and levels of the lavas of conduits. If only to a depth of 200 feet, an average of 20 per cent. of vesicles would add only 40 feet to the height or level of the surface.

But if the vapor particles at all deeper depths are, through their expansive force, undergoing gradual expansion as they work their way or are carried upward, we are still further in the dark as to the amount of effect of vapors on the bulk of the lavas in a conduit. After my observations of 1840, I was led to question, as I state in my Expedition Report, whether the effects from this means might not be sufficient to account for much of the excess of elongation of the Mt. Loa column over that of Kilauea. This is obviously not so. But how much the elongation, is an important question, and it has still to remain unanswered.

4. WORK OF VAPORS GENERATED OUTSIDE OF THE CONDUIT: FRACTURES, DISPLACEMENTS AND OTHER RESULTS.

The conduit has hot rocks around it; and beneath the floor of the crater there are hot rocks about and over its upper extremity. The descending waters are driven back as vapor, and usually in a harmless manner. But a sudden incursion of subterranean waters happening under any circumstances, might produce confined vapors of great force. The natural effects of the pressure of such confined vapors are fractures, elevations and subsidences, and, where pressure is brought to bear in a confined place on a source of liquid lavas, their injection into any open fissure at hand.

These effects belong mostly to times of eruption; but in a lighter form, they may be part of the ordinary work of the crater. The lava-lakes of the bottom, even in quiet times, often have large over-flows, and also out-flows through fissures, that is both *superfluent* and *effluent* discharges; and it is probable that the cause here considered may be the occasion of part of them.

Confined vapors are often generated also by the action of the heat of a lava-flow on moisture underneath. As rains fall almost every day at Kilauea, there must be more or less moisture underneath many parts of the cold floor; and if a few hours flow from the great lake should flood it with liquid rock, its 2000° F. which the bottom of the stream carries along and does not at once lose, would make vapor out of the moisture, having great expansive force. The large dome-shaped bulgings of the lava-streams and other undulations of the surface are thus accounted for on a former page (xxxiv, 356); and many of the steaming fractures of the floor as well as those of the domes may have the same origin.

The next topic under the head of the Ordinary work of Kilauea is "the Ascensive force of the conduit-lavas."

[To be continued.]

HISTORY OF THE CHANGES IN THE MT. LOA CRATERS.

By James D. Dana.

[From the American Journal of Science, Vol. XXXV, April, 1888.]

Art. XXIII.—*History of the changes in the Mt. Loa Craters;* by James D. Dana. Part I. Kilauea. Continuation of the Summary and Conclusions. (With Plates IV and V).

[Continued from xxxiii, 433; xxxiv, 81, 349; xxxv, 15, 181, 1888.]

B. *The Ascensive Action in the Conduit lavas.*

1. *Evidence.*—The evidence in favor of an uplifting action by the ascensive force has been presented in volumes xxxiv, pp. 83, 89, and xxxv, p. 25. It is briefly as follows:

(1) The observations in 1846 by Mr. Chester Lyman demonstrate that in six years the lower pit of 1840, averaging 10,000 feet by 2,500 in its diameters and nearly 400 feet in depth, had gradually become obliterated, and chiefly through an uplift of the floor; for the floor bore on its surface the talus of lava blocks that had fallen from the walls. Overflows had done part of the work, but "subterranean force," as Mr. Lyman concluded, the larger part. Mr. Coan, who was with Mr. Lyman at the time, appreciated the evidence, and later described the lifting as "not uniform in all parts; as sometimes taking place here and there abruptly; but as producing nearly uniform results, except a greater rise toward Halema'uma'u."

(2) In 1868, Mr. Brigham gave further evidence as to the Lyman ridge by the representation of what remained of it in 1865 (xxxiv, 89, and xxxv, 24), on his valuable map, though not, as his memoir shows, understanding its origin. Besides this, the painting of the crater of about the same date (1864 or earlier) by Mr. Perry afforded confirmatory proof as to its position and extent at that time (xxxv, 25).

(3) In 1848, Mr. Coan observed that a cone of broken lava that had formed within the Halema'uma'u basin, was lifted by "subterranean action," as he argued, because only slight addi-

tions were made to its outside by ejections. It continued to rise bodily until it was as high as the near walls of Kilauea (xxxiv, 86). Between 1880 and 1882, another debris cone began in the basin of Halema'uma'u which, as he describes, rose in like manner without additions to its summit, and finally became 200 feet or more high; this cone continued to exist until the eruption of 1886.

The subterranean force appealed to was plainly force arising in some way from the lavas beneath. Mr. Coan, in his letters to me, supposed that the lifting was produced by the injection of the lavas of the conduit into open spaces between the solid layers below.

(4) Again, in the summer of 1886, three months after the eruption of that year, the debris from the falling walls of Halema'uma'u were *seen* to be made into a cone occupying a large part of the interior of the basin; and from August onward, it was apparent that the cone so made was slowly rising, though having little outside additions; in October, its top was on a level with the rim of the basin; in January, 200 feet higher, so as nearly to overtop the southeastern Kilauea walls. It was early apparent to visitors at the crater that the elevation was through action below; and soon the conclusion was general, among observers, that the cone, as expressed in the words of Mr. Dodge, of January 14, 1887, was "rising slowly as though floating on the surface of the new lava-lake.* The mean rate of elevation, according to the heights given, was about two feet a day.†

The ascensive force was thus proved to be great, and its effects to have fundamental significance.

2. *Method of Action.*—It is a question whether, in the lift of the floor of the great crater in 1823, 1832, 1840, 1868, the lavas of the lava-conduit acted by direct thrust, or through injections into spaces between the layers of solidified lava beneath it.‡ The facts favor strongly the former of these views. In the first place, the lateral thrust in the upper lavas of a conduit is necessarily feeble; for the conduit there, or near by, opens to the surface. Then secondly, it is quite certain that the breadth of the Kilauea conduit at top has been, at the times of these up-

* This Journal, xxxiv, 70.

† I was informed, when at Honolulu, by Mr. Parmelee, of that place, that in August of 1886, he made observations on the rate of change of level, by sighting from the Volcano House verandah over a post 100 yards in front of the house, and marking the change of the line of sight on a pillar of the verandah. His observations were made between the 19th and 21st of the month, on the first day of the rise, according to his calculated result, was 16 feet; on the second, 17; and on the third 8 feet. These numbers are large. They were not verified by observations near the cone. They at least prove progress in the elevation.

‡ The latter is the explanation adopted by Mr. Brigham in his paper of July, 1887, xxxiv, 19.

lifts of the floor, large enough to act somewhat equably against the floor. Thirdly, since the floor kept its even surface as it fell at the great eruption of 1840, it must have followed down, as already urged, the subsiding lavas (page 213). The flotation method, or that by direct thrust, seems therefore to be the right one. It is the obvious explanation of the lifting of the debris cones of Halema'uma'u.

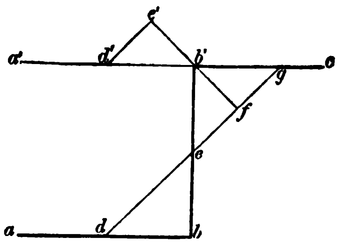
Kilauea affords, as has been indicated, facts illustrating the details connected with the lifting movement.

3. *Fault planes of the up-and-down movements about the pit.*—(1) The down-plunge of 1823, 1832, and 1840 left, for the most part, vertical walls bounding the "lower pit" so made. There is evidence that these were fault-walls, that is, planes of fracture with a vertical displacement along them equal to their height, or about 400 feet in 1840 and 600 or 800 feet in 1823. In the reverse movement, that is, the rise after the down-plunge of 1840, the old floor was carried up along the same fault-planes. The rate of rise, as shown on page 16, was 70 to 130 feet a year, which is to be divided between (*a*) overflows (*b*), vesiculation if this had any effect, and (*c*) ascensive force apart from vesiculation.

Further: these vertical fault-planes of 1840, and others subordinate to them along the border regions, appear to have determined the chief places of eruption, that is, of lava-lakes, cones, ovens and opened fissures in Kilauea *during the next thirty years*. They were plainly the occasion of the wonderful girt of fires, four miles long and half a mile wide, which was three times repeated after the year 1846 before the eruption of 1868 (in 1855, 1863, and 1866), while the interior plateau suffered relatively little change from erupting forces, and in some parts was growing ohelo bushes and ferns.

The position of the "canal" in Kilauea in 1846 described by Mr. Lyman and also by Mr. Coan, as extending around the crater, bounded by the outline of the old black ledge and the Lyman ridge of lava-blocks, and which became gradually filled by inflowing lavas and debris, has here its explanation. The circumferential fault-planes of the pit of 1840 coincided with the face of the lower wall or precipice. The debris which fell from the wall necessarily fell to the floor beyond the plane and there began the making of the talus. Through the fall of the face of the wall, the wall, and thereby the limit of the black ledges, retreated, and as the elevation of the floor went on, an interval was left between the talus and the limit of the black ledge, and along this interval lay the "canal." The annexed figure will serve to illustrate the point, notwithstanding the assumptions made in it. Let *bb'* be the wall of the lower pit, 400 feet high, and the course of the fault-plane;

ab the floor of the pit; *b'c*, the surface of the black ledge. Let now the falls from the wall above *e* make the talus *deb* with a slope of 45°, causing thereby the wall (and limit of the black ledge) to retreat to *g*. If the floor be now lifted 400 feet, to the position *a'b'*, the debris of the talus *deb* would make an elevation at top equal to *d'e'b'*, besides filling up *efb'*, ($efb' = d'e'b' = \frac{1}{2}deb$); the interval *b'fg* would represent the canal, and *d'e'b'*, 100 feet high, the ridge.



If the floor were raised 50 feet higher, the ridge would be lowered, say 25 feet, owing to material that would slip down into the canal; and consequently, the height of the ridge above the floor over the center of the crater would then be 25 feet less than before, while 25 feet more than it was above the black ledge. If no talus had been formed at the foot of the wall, an uplift of the floor of 500 feet would have made a precipice of 100 feet fronting toward the black ledge, the falls from which would have produced a steep talus. These are two conditions in the different parts of the ridge mentioned in Mr. Lyman's paper.

(2) *Fault-planes about Halema'uma'u.*—In Halema'uma'u at the eruption of 1886, there was a circumferential fault plane; this seems to be implied in the fact that the return of lava was mostly through vents toward the walls, little coming up at the center; and the fact that even a year and a half afterward, the action was greater outside of the cone than at its center. At the discharge, the debris from the tumbling walls fell beyond the fault-plane and made an accumulation of blocks, like the talus of the lower pit of 1840, and this, as Mr. Dodge's description shows and the photographs illustrate, was the material that became the cone as the lifting went forward.

(3) *Conclusion.*—By the above facts, it is proved that the conduit lavas of the volcano not only keep up the supply of heat, and carry on, by means of the vapors, projectile action and vesiculation, but also that they furnish power for lifting, in a quiet, unperceived way, the floors of craters with whatever is upon them, and thus raising the level of volcanic activity; and that this goes forward as part of the *ordinary* operations of the crater. The action has long been recognized as a means of supplying heat and lavas, but not as a mechanical agent to the extent here indicated. The force at work in making the Gilbert laccoliths must be the same, and Mr. Gilbert, in his

report on the Henry Mountains, gave the first intelligible idea of its power.

But there is nothing in the action that leads us to suppose that it can, under any probable conditions, make jets or fountains of lavas, or work in blow-hole style. Each jet over a lake, and each large jet in a lava-fountain, has its local projectile cause beneath the projected column of lava, and cannot be produced by any general upthrust movement in the great conduit. The imperceptibly slow uplift and fountain-making are incompatible effects. There seems to be, therefore, no foundation for the comparison of the lava fountains to the projectile effect in an "artesian boring made to a stratum of molten rock which had only been awaiting an opportunity to overflow."*

The *source of the ascensive movement* I have stated to be undetermined. It is most commonly referred to the pressure of the earth's crust on the lava reservoir beneath, arising from subsidence in the earth's crust from secular refrigeration. Another explanation appeals to vapors from the deep source of the lavas. The possibility of some addition to the force through ascending vapors is referred to on page 195 of this volume.

C. *Effects of Heat.*

1. *From change of temperature.*—Contractional effects from cooling, that is fractures and changes of level, should be common in the crater; for each stream has passed from a temperature of 2000° F. or more to 70° or 80° F. and the upper surface of a stream rapidly so. Besides ordinary shallow fractures, the cause produces also an imperfectly columnar structure in the cooled lava-stream below the upper foot. The cracks in the floor often expose quite good basaltic columns even when the thickness of the layer is hardly a dozen feet.

There should be also larger effects in the Kilauea region arising from change of temperature between periods of great and little activity, or from periodical variations in the heat below, and changes of level in the lava of the conduit. But we have no special facts to report in illustration, although there are cracks innumerable in view that probably have this source.

2. *The dissolving action of the liquid lavas.*

(1.) The *refusion of the crust* over the surface of a lava-lake by the liquid lavas is—as the history has shown—one of the common occurrences in Halema'uma'u and other lava-lakes.

* Mr. W. L. Green, Vestiges of the Molten Globe. pp. 168, 272. Mr. Green's examples are taken from action in the summit crater, and when speaking of that crater this point will be again considered.

The intervals of cooling and refusion vary in length from a few seconds to an hour and longer. The crust of a lava-lake is often only the thin, easily fusible glassy scum, but thicker crusts also yielded to the heat.

In the case of rapid transitions, the cooling and refusion may be due to the loss of heat by the expansion in the process of vesiculation; and if the vesiculation takes place intermittently for any reason (as from oscillating movement in the lava column, or other condition) it would occasion the alternations between the fused and crusted state. But for the crustings at longer intervals deeper movements may be concerned, and more study is needed before they are fully understood.

(2.) *The disappearance of floating islands* is another effect of heat and chiefly of refusion. For in some cases the islands have after a while—a year or more—disappeared.

(3.) *The destruction of debris-cones* in Halema'uma'u is dependent on undermining by the active lavas and vapors beneath; and, in one case, the destruction was probably completed before a period of eruption (xxxiv, 88).

The debris-cone, 1500 to 2000 feet broad at base, which now occupies the center of the Halema'uma'u basin is already in process of dissolution. It made no increase in height during the summer of 1887, but, instead, rather lost ground through the changes going on. This fact was obvious in August last; for the east wall, a single continuous ridge in October, 1886, had become divided into two ridges, and dense vapors rose from the interval between, with sounds of splashing lavas that were evidence of an active lava-lake below A photograph taken in October, 1886, copied on Plate IV, shows the condition of this side of the cone at that time when it had reached its maximum height; and Plate V, from a photograph taken nearly a year later, in September last (a month after I left the crater), exhibits the condition above described. Both views were taken looking westward, and the foreground in each is the bottom of Halema'uma'u on the east side of the cone. In Plate IV dense vapors may be seen issuing from a large aperture near its middle, and other vapors from a lower place to the right (north). In Plate V, the vapors escape copiously *all the way between* these two places and far southward, showing the subdivision nearly completed. A photograph taken in the spring of 1887 exhibits an intermediate stage in the process of division. A letter of Jan. 2 of the current year, from Mr. J. H. Maby, proprietor of the Volcano House, says that the bottom of the Halema'uma'u basin on the east side (that shown in the plates) has risen much and is now nearly on a level with the upper surface between it and "New Lake" and a lava-lake has opened in it, so that the fires and the overflows are visible from the

Volcano House, and "to all appearances, the lavas will soon be running into New Lake."

The description given by Professor Van Slyke of the cone as seen by him in July, 1886, gives particulars as to the steam-holes in and beneath the cone, and the blowing-cone work, which began this work of destruction and prepared the way for the subdivision. He states that he ascended the cone to a perpendicular well, which opened through its side by a hole "30 or 40 feet wide and 60 to 75 feet long," and looking down to the bottom 100 feet below, saw the lavas rising and falling in jets from a small vent. In another well of like depth, 20 to 30 feet in diameter, there was a cone and "lava boiling with intense violence" (xxxiii, 96).

This destructive work brings the cone to its end either before, or during, a period of eruption; and a floating island may be the last phase before its disappearance.

(4.) *Opening of new lava lakes.*—With the intensifying of the fires of the crater there has often been, as the history shows, an opening of lakes over the interior of the crater, and especially along the borders of Kilauea, or the region of the black ledge. Such facts signify, as I have explained, that the broad underlying conduit of Kilauea, which is like a great reservoir of lavas beneath the pit, reaches at such a time up to the surface, not only in the Halema'uma'u basin through the great conduit, but also in minor lakes through secondary conduits. It is a query whether this has ever been brought about by new sources of vapor starting in the underlying reservoir, as a consequence of subterranean conditions; whether hot vapors from such a source have not forced a way through to the surface in consequence of their own dissolving and fusing heat and that of the lavas, and thus have made a new lake;—as ascending air from the bottom of an ice-covered pond makes a hole through the covering of ice. But such lakes, as remarked on a preceding page, are generally begun over fissures, and it may be that fissures, under the general increased activity, are all that are needed for the result.

(5.) *Extending the limits of the conduit by fusion.*—Another suggestion comes from the fusing power of the Halema'u-ma'u lavas. If these lavas can slowly, even at their surface, fuse stoney lavas, what is the extent of the fusing power at depths below where there is greater heat? An increase in the heat from a subterranean cause would necessarily widen the limits of the conduit. It is a question whether an extended subterranean bed of liquid lava, thick enough to remain permanently liquid in spite of cooling agencies about it, can occupy its place without fusing and incorporating with itself any solid lavas directly underneath it, if such there be? A

great lava-conduit, therefore, has probably its varying phases, like the fires at the surface, and includes extremes in breadth or enlargement as well as in contraction. The widest part should not be at the summit unless the cooling agencies are *less* effective, or the heat-making causes more so, there than elsewhere.

3. *The metamorphic action of the heat.*—Metamorphic action also may be part of the quiet work of the volcano. The lava-column has its enclosing rocks, and at temperatures varying from that just below fusion to that of the outside rocks; and vapors must be active in the hot regions. The throat of the conduit may well be, therefore, a region of recrystallizations, of the making of geodes, or lining fractures with crystals, out of whatever material was at hand, and differing somewhat according to the temperature. The effects of such metamorphism are exhibited, beyond question, in the various mineral crystallizations in the ejected masses of Vesuvius. They are found also at Kilauea and will be mentioned beyond.

D. *Hydrostatic and other Gravitational Pressure.*

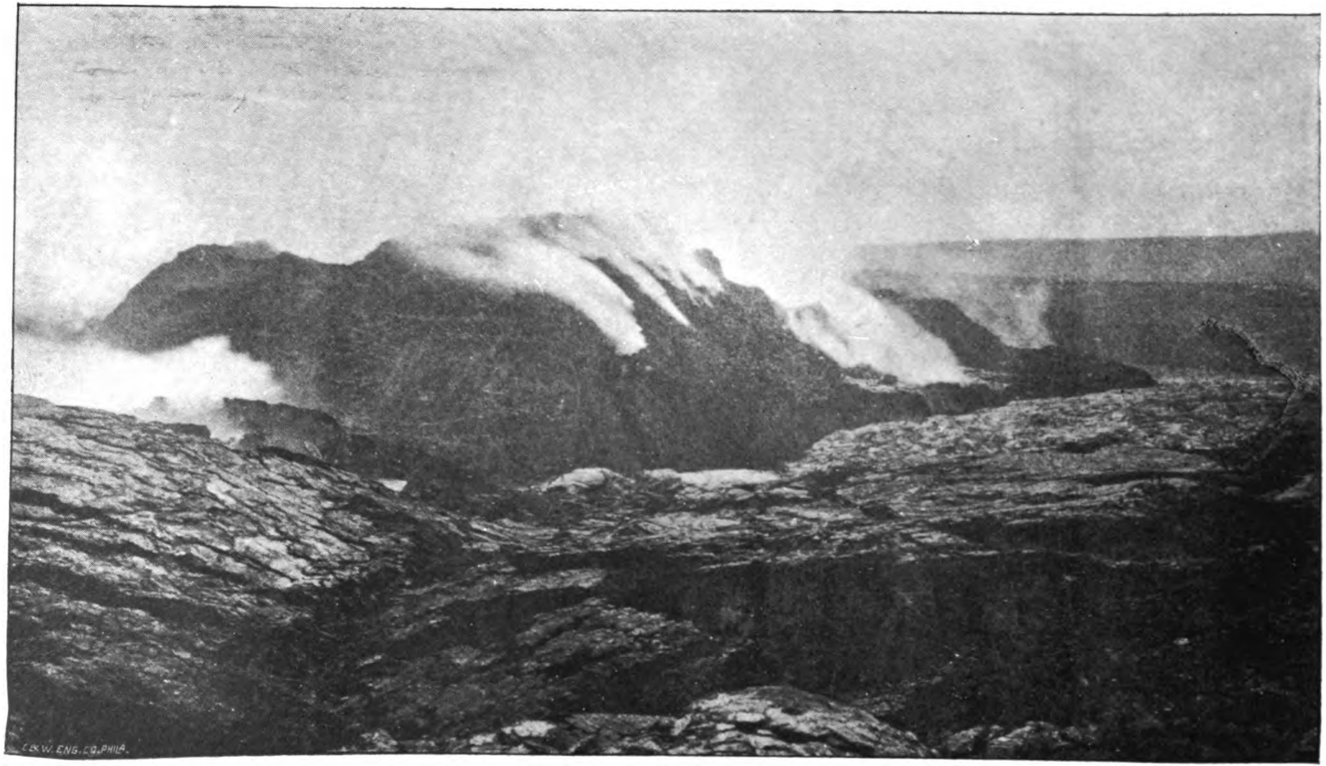
1. The hydrostatic pressure of the column of liquid basalt is 2·8–2·9 times that of water, supposing the lavas while in fusion to be mainly in the glassy condition. This pressure was early recognized by Lyell as one of the possible causes of rupture in volcanoes. The cause may have its effects in a quiet way over the bottom of Kilauea, since the lavas often stand in the lakes at a height of 50 to 100 feet above the floor outside of the surrounding cone; but no facts yet observed can be positively referred to it.

2. Again, there may be *underminings* and therefore *subsidences* in the ordinary course of Kilauea changes, through discharges following small fractures. But such effects are not at present distinguishable from those of other modes of origin.

Having thus reviewed the ordinary operations of the crater, that is, those carried forward between times of eruptions in the way of preparation for an eruption, the next enquiry is, What is needed to produce a great eruption of Kilauea? The power of the rising vapors and that of the ascensive conduit-lavas, the two chief sources of ordinary activity, appear to be too feeble for any such result. Can eruptions take place without any increase of their activity within the crater beyond what has been described? If so, how?

Before discussing this subject, the history of the summit crater, Mokuaweoweo, may be first reviewed, as its facts afford important illustrations of the eruptive methods.

[To be continued.]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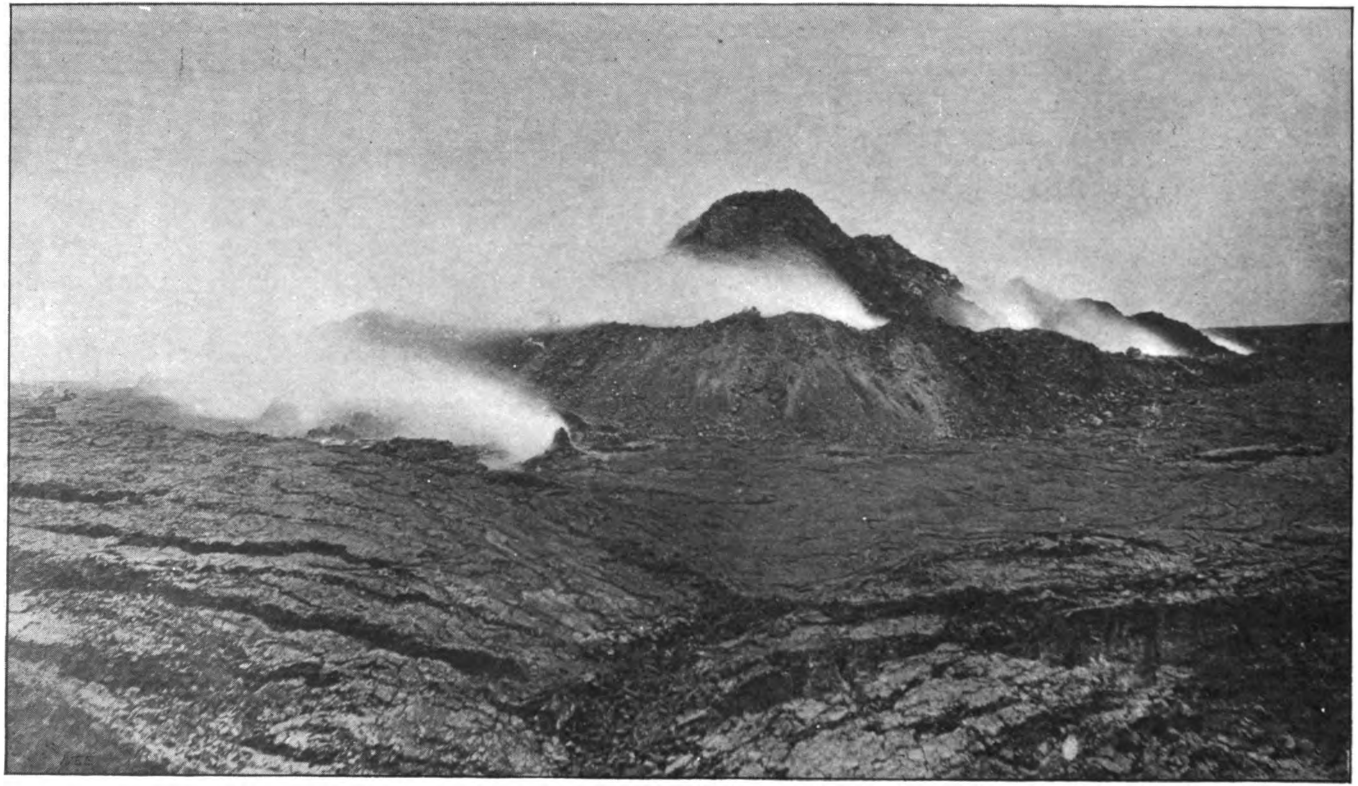


HISTORY OF CHANGES IN THE MT. LOA CRATERS.

By JAMES D. DANA.

With Plates I, II, III.

[From the American Journal of Science, Vol. XXXVI, July, 1888.]

Art. II.—*History of Changes in the Mt. Loa Craters;* by James D. Dana. With Plates I, II, III.

[Continued from page 289; and also from xxxiii, 433, xxxiv, 81, 349, xxxv, 15, 181.]

Supplement to the History of Kilauea.—Since the debris-cones of Halema'uma'u, the great lava-lake of Kilauea, have a constitution and history unlike anything thus far reported from other volcanic regions, I add to the previous notes the following from a recent letter of Mr. J. H. Maby, of the Volcano House, dated March 8th. Mr. Maby writes that the cone has been rising since August, of 1887, until now the summit is "on a line with the outside walls of the crater, looking from the Volcano House." No additions have been made to the exterior, but instead, the eastern side (which Plate 5 in the last volume, from a photograph, showed to be in process of separation from the rest) "has slipped down a little and changed considerably its shape." Moreover the bottom or floor of the Great Lake with its lavas, is now within 40 or 50 feet of the top, which implies a rise of 30 or 40 feet in the same interval. The fires have been very active, and are now visible, from the house, on the *east* side of the cone; and the lavas on that side have flowed over into the deserted basin of New Lake, filling its lower portion. The lake on the west side of the cone has also much increased in size, being now nearly 300 feet in diameter; and it has thereby encroached on the doomed cone.

II. MOKUAWEOWEO, THE SUMMIT CRATER OF MT. LOA.

Maps.—A map of the island of Hawaii, reduced from the Government map, is here introduced (Plate 1) for the better illustration of the facts and discussions beyond.* It shows the topographic simplicity of the island—a fact not expressed in most of the small published maps, which generally (like that of the eleventh volume of the new Encyclopedia Brittanica) put in mountain ranges or ridges that do not exist. The map will enable the reader to appreciate the relative position of Kilauea and the Mt. Loa crater, their relative heights, the absence of water-courses from all of the mountain slopes except a small windward region; the large size of the valleys of the Kohala Mountains to the north; the positions of the great lava streams of 1840 to 1887; the routes of the roads (mostly bridle paths); the two routes to Kilauea, one of thirty-one miles on horseback from Hilo, the other of about half this distance, from Keauhou, the upper half a good carriage road; and also the districts into which the island is divided, and the positions of the principal villages.

The present form of the summit crater, Mokuaweoweo, is shown on the map by J. M. Alexander, Plate 2, reduced from the results of his survey. The height of the highest point, given on it, 13,675 feet, differs eighty-five feet from Wilkes's determination of the same point in 1841.

The *history* of the summit crater is mostly a history of the results of its eruptions, for few facts have been observed about the action *within* the crater. It has excited attention when an eruption has been in progress; but the chief outflows have begun below the summit and the source of the outflow is usually the only place reached. Still there is much to be gathered from the reported facts. My personal investigations have been confined to the base of the mountain, and the review beyond is hence almost solely from the accounts of others.

History of the Eruptions from 1832 to 1888.

1832, *June* 20.—On the 20th of June, 1832, according to Rev. Joseph Goodrich, lavas were discharged from several vents about the summit. The fires continued to be visible for two or three weeks, and were seen from Lahaina, 100 miles to the northwest. Nothing is known of any large discharge of lavas, and no mention is made of accompanying earthquakes.

*The Government map, as stated upon it, is only a preliminary map, part of the survey being still incomplete.

† Goodrich, this Journ., xxv, 201, 1834, letter of Nov. 17, 1832.

The outbreak of Kilauea in 1832 occurred about the same time, but possibly a few months later (xxxiii, 445, 1887 and xxxv, 15, 1888).

1834, *January* 29th.—Mr. David Douglas, the naturalist, who was the first to ascend Mt. Loa, describes the crater, in his Journal,* as having great chasms in the bottom that he could not fathom "with a good glass and the air clear of smoke:" and says further: that "the depth to the bottom on the east side was by an accurate measurement with a line and plummet, 1270 feet;" that the southern part of the crater, "where the outlet of the lava had evidently been, must have enjoyed a long period of repose." He mentions hearing light hissing sounds from fissures in the summit that might "perhaps be owing to some great internal fire escaping." He adds, "There is little to arrest the eye of the naturalist over the great portion of this huge dome, which is a gigantic mass of slag, scoriæ and ashes."

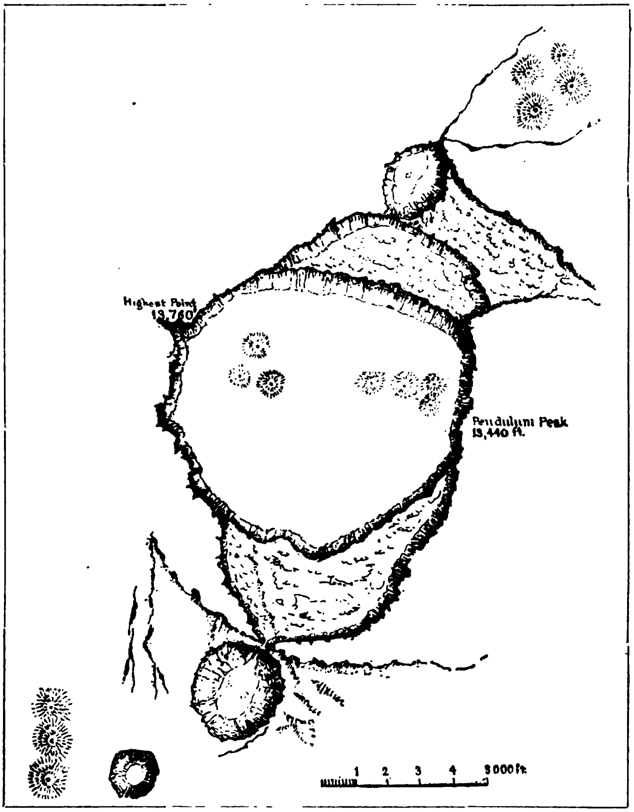
1841, *January*.—Captain Wilkes was at the summit during the latter part of January, 1841.† Lieutenant Eld, by taking angles from the bottom of the crater, made the western wall 784 feet high, and the eastern, 470 feet. The only sign of activity was the escape of steam and sulphur gases from many deep fissures over the bottom, especially on the west side. The fissures had generally a N.N.E–S.S.W. direction. There was one cinder or scoria cone at the bottom, according to Dr. Judd, toward the southwest side, having a height of about 200 feet. Other steam cracks were observed outside about the pit crater of the south-southwest end; and one, which they "designated the great steam-crack, led from the top of the mountain a long distance down its sides toward the south;" and a great depth was indicated by the reverberations from a block of lava which was dropped into it. Small driblets of lava were observed along some of these fissures; indicating feeble ejections at the very summit. In Wilkes's map, as shown in the outline copy on the next page, seven small cones are faintly represented on the bottom of the crater, although the descriptions speak of only one.

1843, *January*.—In January of 1843 began one of the great outflows. It continued for about six weeks. Clouds above on the 9th made the first announcement to the people of the

* Companion of the Bot. Mag., ii, 175, 1836, and in a letter to Capt. Sabine, dated May 3, 1834, Journ. Geogr. Soc., iv. 333, 1834. See this Jour., xxxiii, 436, 437, 1887, on the letter to Dr. Hooker and the evidence against it.

† Narrative of the Exped., iv, 152, 156, 159. The descriptions of the crater are from descents made into it by Dr. Judd of Honolulu (on p. 152) and Lieut. Henry Eld (on p. 156). Wilkes's map has its longer diameter, through some mistake, north-and-south in direction.

islands. During the following night, according to Dr. L. Andrews,* a brilliant light appeared at the summit, looking, as Mr. Coan states, like "a small beacon fire."† In a week



The Summit crater, after Wilkes, January, 1841.

the light disappeared. In the mean time the lavas had commenced their discharge. Mr. Coan ascended to the source, about 13,000 feet up, and found two large craters near together, very deep and active. The source given on the map is at least 2000 feet lower. The stream of lava flowed toward Mt. Kea, but gave off a westward branch, toward Hualalai, near its source. At the base of Mt. Kea, a branch went northward toward Waimea, and another eastward toward Hilo. Mr.

* Andrews, Missionary Herald, xxxix, 381, letter of Feb. 6, 1843.

† Coan, ibid., xxxix, 463, letter of Feb. 20, 1843; xl, 44, letter of April 5; this Journal, II, xxvii, 411, 1859; Life in Hawaii, 1882, p. 270.

Coan states that over the crusted surface of the stream were many steaming openings 20 to 50 feet broad, down which he saw the lavas rushing along the tunnel-like way, "with awful speed, some fifty feet below us;" large stones thrown on the surface were carried "instantly out of sight before sinking into the stream." The action was much diminished in six weeks, but was "still somewhat vehement at one or two points."

Mr. Andrews states that during the progress of the eruption Mr. Wilcox visited Kilauea and found no signs of sympathy.

1849, *May.*—A brief notice of brilliant fires at the summit crater in the month of May, 1849, is contained in a letter of Mr. Coan's, dated January, 1851. He says, that the light was first noticed *after* the extraordinary activity in Kilauea. "I cannot say that they were coincident." For two or three weeks, a brilliant and lofty column of light was seen over the mountain. There is no reported evidence as to any surface outflow of lavas, and none of an earthquake.*

1851, *Aug.* 8.—A short flow commenced at this date a few miles west of the summit.† From Hilo, a column of clouds was seen by day, which was fiery by reflection at night. The eruption continued, as far as could be seen from Hilo, only three or four days. No earthquake was reported.

Mr. Wm. T. Brigham in 1864 visited the flow, and states‡ that the outbreak of 1851 occurred about 1000 feet below the summit "or 200 feet below the bottom of the crater." He estimated the length of the stream at "ten miles and the average breadth less than a mile," and the volume, "160 million cubic yards of lava." "The greater part is the pahoehoe, although some aa occurs." The course was westward, near that of an old stream toward Kealakekua.

1852, *Feb.* 17.—One of the greatest of the Mt. Loa eruptions began on the 17th, only six months after the eruption of 1851, as if its supplement. The place of outbreak, according to Mr. Coan,§ was on the north side of the summit, near that of 1843. When first seen, the light looked like "a planet just setting" over the top of the mountain. In a few minutes the whole summit was brilliant, and Hilo also; and a stream of lava commenced its flow down the mountain. Forty hours later the fires had apparently become extinct.

After three days, on the 20th, the chief flow began at a point on the eastern side about 10,000 feet above the sea-level, near

* Coan, this Journal, II, xii, 82, 1851. letter of January, 1851.

† Coan, this Journal, II, xiii, 395, 1852, letter of October 1, 1851; and D. D. Baldwin, ibid., p. 299, from "Polynesian" of Aug. 23, 1851.

‡ Volcanoes of the Hawaiian Islands, 4to, 1868, p. 389.

§ Coan, this Jour. II, xiv, 105, 219, 1852; Life in Hawaii, p. 279.

the terminus of a line of fissures leading down from the place of the first outbreak. *The escaping lavas rose at first in a lofty fountain*, and then flowed eastward for twenty miles. On the 27th, Mr. Coan reached the place of the fountain approaching it on the windward side within 200 feet. He found the lavas playing, as he states, to a height of 400 to 500 and 700 feet, by angular measurement, in ever-varying forms of towers, pyramids and spires, and with variations also in colors from white heat at base to red above and then to grayish red and gray.

Great volumes of lava were ascending and descending, not intermittently but continuously; and the "surging, roaring, booming" sounds were almost deafening, but without earthquake from beginning to end. Ashes and capillary glass fell in the streets of Hilo. The stream stopped about ten miles from the village. The grand eruption was in blast only twenty days. All this time Kilauea was quiet.

In July, Mr. Coan ascended again to the crater or place of discharge* and found the fires extinct. He says, a kind of "pumice" was abundant and widely scattered; "we found it ten miles from the crater, and it grew more and more abundant till we reached the cone, where it covered the whole region to a depth of five or ten feet."

An ascent to the active fires was made early in March by Mr. H. Kinney† and Mr. Fuller. Mr. Kinney, speaking of the sounds from the cataract of liquid lavas, says: "its deep unearthly roar, which we began to hear early on the day before, waxed louder and louder as we drew nearer the action, until it resembled the roar of the ocean's billows when driven by the force of a hurricane against a rock-bound coast, or like the deafening roar of Niagara." This description attests to the fountain-like character of the discharge; for such sounds do not come from flowing lavas unattended by earthquake phenomena. Mr. Kinney made the height of the jets 400 to 800 feet. He reports also, that the heat created terrific whirlwinds which stalked about like so many sentinels, bidding defiance to the daring visitor.

Mr. Fuller states,‡ that from careful calculations made, "after deliberate discussion with Mr. Kinney," "some of which," he says, "have been confirmed by a somewhat accurate measurement by Mr. Lyman of Hilo," the diameter of the crater from which the fountain rose was about 1000 feet; height of the crater, 100 to 150 feet; height of the fountain,

* Coan, ibid., xv, 63, 1853.

† H. Kinney, this Journal, II, xiv, 257, 1852, from the "Pacific" of San Francisco of June 19, the letter dated Waiohinu, Hawaii, April 19, 1852.

‡ Fuller, this Journal, xiv, p. 258, 1852, letter dated Waiohinu, March, 28.

200 to 700 feet, and rarely below 300 feet; diameter of the fountain, 100 to 300 feet, "and rarely perhaps reaching 400 feet." The jet of fire sometimes shot up into a tapering gothic spire of 700 feet, then rose in a grand mass 300 feet in diameter, but varied at top with points and jets like the ornaments of gothic architecture. He adds that to appreciate the most terrific element in the sublime composition you should stand at the foot of a Niagara, or on a tempest-lashed shore; for "the force necessary to raise 200,000 to 500,000 tons of lava at once into the air would not be silent in its operation." The lava stream is stated to have a depth, in some places, of 200 or 300 feet.

1855, *Aug.* 11.—During the evening of August 11, a glowing point of light was seen at a height of 12,000 feet on the northeast slope of the mountain.* The light rapidly extended, and it soon became evident that a lava-stream was on its way down the mountain. No earthquake had announced the eruption.

Mr. Coan ascertained, through his excursions, that a line of fissures extended from near the summit for five miles down the northeast side to the place of outbreak, along which there were cones of volcanic scoria and sand 100 feet or so high, that had been thrown up at the points of greatest activity. Descending the mountain, the cones became lower and less frequent, and were the ragged jaws of orifices through which the stream of lava was visible.

The place of outflow was a crater formed over a fissure two to thirty yards wide. The lava flowed in a continuous stream down slopes of all angles from less than one degree to verticality. The course was eastward like that of 1852, and it finally stopped within five miles of Hilo.

Mr. Coan describes the tunnels in the lava stream, and speaks of the lavas seen through openings, as moving with great velocity—"estimated to be 40 miles an hour." Some of the steaming openings were 30 to 200 feet long, and the flowing lavas were 50 to 100 feet below. But the progress of the front of the stream, where were obstructions of trees, jungles, depressions, etc., was "slow—say one mile a week." He observes that owing to the cooling, and the partial damming thereby along the front, the hardened upper stratum was raised by the descending stream into numerous tumuli of various forms and sizes as if by pressure from above, which became cones or domes, and let out lavas to flow over the surface and add to the

* Coan, this Journal, II, xxi, 144, 139, 1856, letters of Sept. 27 and Oct. 15, 1855; ibid., p. 237, letter of Nov. 15, 1855; ibid., xxii, 240, letters of March 7, 1856; ibid., xxiii, 435, 1857, letter of Oct. 22, 1856; Life in Hawaii, p. 289.

thickness; that "upgushings" also occurred through fissures; and that thus layer was added to layer, increasing the thickness from a few feet to 50 or 100, and also retarding the progress of the stream. One dome on the stream was 100 feet high and 300 in diameter; and through the fissured top and sides the liquid lavas were visible, and easily reached by the pole he had for measuring the thickness of the cap—2 to 5 feet. These effects were especially great where the slope was very small. Pressure of the lavas above, and gases or vapors from the burning of trees and other vegetable matter buried by the lavas, are made the causes of the uneven surface of the lava stream.

The stream, in addition, became widened by the lateral outgushings, divided into a number of channels, and shifted to the right or left. After flowing freely for a while, the stream often suddenly cooled and hardened along the front and remained for several days inactive; "at length, immense areas of the solidified lava, four, five, or six miles above the extremity, are again in motion, cones are uncapped, domes crack, hills and ridges of scoria move, immense slabs of lava are raised vertically or tilted in every direction."

On the 22d of October, 1856, the stream was within five miles of the sea-coast north of Hilo, still pushing out and spreading itself. Mr. Coan says that the lavas were even then flowing in the tunnel-ways from the place of outbreak to the lower extremity although no fires were seen—evidently an opinion rather than a direct observation. He argues for the absence of fissures beneath the stream for the supply of lava, from the absence of steaming vents and cones. After 15 months, in November, the fires ceased action. The stream includes many square miles of aa and immense fields of pahoehoe.

1859, *Jan.* 23.—Another great eruption began at this date. Prof. R. C. Haskell (of a party visiting the eruption consisting also of Prof. Alexander and President Beckwith) reports* that "smoke" was seen over the summit from Waimea by Mr. Lyons of that place on the 23d. In the evening, lavas were ejected, and the light was bright enough at Hilo, 35 miles east, to read fine print. "No earthquake was felt in any part of the island." But dead fish, apparently parboiled, were found in the sea to the northwestward, both east of Molokai and between Molokai and Oahu.

* Haskell, this Journal, xxviii, 66, 284, 1859, (the latter from letter of June 22); xxix, 301, 1860, letter of Nov. 5. There are shorter reports by Editor of Commercial Advertiser of Oahu and Rev. L. Lyons, ibid, xxvii, 412, 1859; and Coan, ibid. xxvii, 415, letter of February 2, 1859, and xxix, 302, letter of Nov. 25, 1859. W. L. Green, "Vestiges of the Molton Globe," 1887, pp. 163, 270, 280.

The stream flowed northwestward by the northeast foot of Hualalai and reached the sea on the 31st of January at Wainanalii, a dozen miles south of Kawaihae, a distance in all of 33 miles in eight days. The chief source was probably about 10,500 feet above the sea level. Above this point for four miles, a fissure, two inches to two feet wide, descends the mountain from which some lavas escaped. Several cinder cones stand along the line of fissures, and two of them near its extremity. Half a mile farther down the outflow began.

The lavas, "white hot" as they escaped, were thrown at once into a fountain, as at the 1852 eruption, the height of which, according to Mr. Vaudrey, who happened to be on the mountain at the outbreak, was 300 or 400 feet.

On the 9th day of February, the issuing lavas were "at a white heat and apparently as liquid as water." The report says that the stream below dashed along in cataracts and rapids at such a rate that "the eye could scarcely follow it." For eight to ten miles there was a succession of cascades and rapids, some of them a consequence of obstructions met on the way and others due to the obstructions which the stream made. The lava flowed more gracefully than water and with great velocity, following the surface beneath, rising as it rose, and turning abruptly, with the outside of the stream higher than the inside, the mobility being perfect.

Both *pahoehoe* and *aa* were formed. The aa portions are described by Prof. Haskell as produced by deep lava streams; streams flowing sluggishly where the slopes are small; which become dammed up in front by the cooling, by the breaking up of the cooled barrier and crust, and by the rolling over and over of the stream. Often at the end of the aa stream no liquid lava can be seen, and the only motion is the rolling of the jagged rocks of all sizes down the front of the embankment. Sometimes it breaks through the embankment, and flows on "carrying jagged rocks of all sizes on its back, which look like hills walking;" then it gets clogged again, with finally a repetition of the process of breaking up and piling.

The stream after reaching the seashore continued flowing into the sea till after the 25th of November. The surface of the stream was of black hardened lavas; but at the sea-border, the liquid lavas ran out at a red heat, having flowed under cover, Prof. Haskell states, for at least 25 miles, if not from the source.

According to Mr. W. L. Green the column of vapor that rose from the orifice or crater, along side of which his tent was pitched, was 500 feet wide and 10,000 feet high. He says, "From the whole interior of the crater rose the great illuminated column of smoke perpendicularly, and then at a great

height in the atmosphere it spread out on all sides." It continued for many weeks, but ceased before the flow was ended. The lava appeared to have broken out at the intersection of two fissures. Over the surface in the vicinity, there was a thick deposit of "pumice" or "glass-foam." The top of the mountain at the time was covered with snow—a source of percolating water. While he was near the stream, on the plain between Loa, Kea and Hualalai, loud explosions were heard all night long, like the reports of heavy cannon."

Mr. Green also states, from his observations, that at the seashore, it ran over a low shelf about ten feet high and perhaps 500 or 600 feet wide and fell into the sea where the water was 20 or 30 feet deep. "It came from under the crust in great red-hot flattened spheroidal masses, having something the appearance of moderately thick porridge as it is poured from a saucepan—the spheroidal masses perhaps 10 to 15 feet wide and 4 to 6 feet deep" "There was no steam, vapor or gas whatever to be seen coming from the lava until it went under water. Indeed the first contact of the red-hot spheroids did not seem to produce a particle of steam, and it was only when each had gone under water and become partially cooled off that a puff of steam rose above the water"—"an effect due to the spheroidal state of the water against the red-hot surface."

No sympathy was exhibited by Kilauea. Mr. Coan says "we have occasional earthquakes: two in February, one in July and two in November of the current year (1859)."

In June, according to Prof. Haskell, there was no action in the summit crater.

1864, *August* 5.—Mr. W. T. Brigham found the summit crater, at this date,* without any signs of action excepting some "steam issuing from the northern bank." There were two cones at bottom, about 200 feet high, near the east side. He also observes that in various places over the great plain about the crater there "were large irregular masses of a solid reddish clinkstone, much used for stone axes," and speaks of the "hard compact graystone of the summit and walls."

1865, *December* 30*th*.—Light was seen "at the very summit," on the night of the 30th of December.† It continued, with variations in intensity, sometimes very brilliant, at others faint or gone, for four months, or until the last of April, or perhaps into May. Mr. Richardson, proprietor of the Volcano House, reported the occasional escape of steam, but no outflow of lava is known to have occurred. "The falls of snow

* Memoir, p. 384.

† Coan, this Journal, II, xli, 424, 1866, letter of Feb. 27, 1866; and xliii, 264, 1867, letter of August 31, 1866.

on the mountains this winter have been frequent and heavy, extending almost to their bases." No earthquakes were reported. "As it was winter, no one ascended the mountain." In May, a great increase of activity began in Kilauea.

1868, *March 27th.*—On March 27th, Friday, many slight earthquakes were felt in Kau, southern Hawaii, and in Kona, the southwestern district. On the 28th they were more energetic and frequent, and extended east to Hilo, and northward through Kona. Mr. T. D. Paris, of Kealakekua, south Kona, reports* that on the morning of Friday, fire and great columns of "smoke" were seen at the summit; and on Saturday the 28th, the fires were visible from Hilo, according to Mr. Coan.† Mr. F. S. Lyman reports, from Kau, that the first outbreak was a little to the southwest of the summit; that others followed, and soon the lavas were seen in four streams running down the mountain in a southerly and easterly direction. By Sunday (the 30th) the line of smoke had advanced about 15 miles on a line toward Captain Brown's house in Kahuku; but the light of the summit had disappeared; it was not seen at Hilo after the 28th. During this time the earthquakes became still more violent and destructive, and almost continuous. On Thursday, April 2d, at 4 P. M., occurred "the terrible shock," destroying houses and life, making fissures of great length and depth, dislodging rocks and half a mile in breadth of marshy earth from the mountain side of Kapapala, to the destruction of a native village, besides raising earthquake waves on the southern coast, that swept away the villages of Punaluu, Ninole, Kawaa and Honuapo. The position of the land-slide is shown on the map of Hawaii, Plate I. It was also violent to the eastward in Hilo, the only stone building being thrown down, and furniture in other houses; but so light on Oahu, 200 miles to the westward, that most of the inhabitants of Honolulu were unaware of it, those in stone houses being almost the only persons that felt it.

On the 7th of April, the lava escaped from a wide fissure in the district of Kahuku. Along this fissure, in the course of a mile, the escaping lavas were thrown into four fountains, which were playing on the 10th, when the place was visited by Mr. H. M. Whitney, of Honolulu. According to this writer's description, the fountains rose to a height of 500 to 600 feet, along the line of the fissure for a mile. The lavas were "blood-red, yet as fluid as water." Sometimes two of the fountains joined, and then all four were united. At one time they subsided for a few minutes, and then burst out

* Paris, this Journal, II, xlvi, 107, 1868.

† Coan, ibid., p. 106; F. S. Lyman, ibid., p. 109; H. M. Whitney, ibid., p. 112.

again and went to a height of 1000 feet. Large stones and rocks were thrown up, some weighing 100 tons; and so many that they seemed to fill the air. The lava of the fountains is stated to have had a rotation "to the south." Below the fountains, the lava flowed in a rapid stream to the sea, making a descent of 2000 feet and reaching the shore in two hours. The rate of flow is stated to have been 10 to 25 miles an hour.* A cinder or tufa cone was made at the place of discharge into the sea, which was first an island, and afterward became joined to the land by the flowing lava. The eruption ceased in the night between the 11th and 12th, after only five days' activity. The lava is mostly pahoehoe, with some areas of aa, and extremely chrysolitic. At the crack above the main outburst, the lava which escaped was light brownish scoria, which was drifted by the winds, along with much capillary glass. The season was one of unusual rains over the mountain.

Prof. C. H. Hitchcock examined the region of eruption in June of 1885, both above and below the extremity of the pali (precipice) represented on the map by the west side of the lava-stream. He states the following facts in a letter, of May 30, 1888, to the author. The fissure whence the lavas of 1868 flowed "is in exact continuation of the pali, up the mountain. I traced it fully three miles. For much of the way it makes a narrow cañon 40 or 50 feet wide at the maximum, and so deep that it is dangerous to explore it. In the lower part heat was still evident. The fissure is most prominent where the lava is in greatest amount. Its borders have the smoothed appearance that would result from an outflow of lava over its edge. The very uppermost point reached we estimated, from our aneroid, to be 3100 feet above Mr. Jones's ranch near the north end of the pali. There is no cone at that point, as there is at the sources of the 1855 and 1881 flows which I also visited. Every fact harmonizes with the view of a rent three miles long, allowing the accumulated lava to discharge in one or two days' time, instead of oozing out of a single small orifice for months. The connection of the fissure with the pali shows clearly the existence of a fissure along its whole length, which has been the seat of eruptions in ages past. This Kahuku flow was analogous to that of Kilauea in 1840.

1870, *January* 1.—During the first two weeks of January, much "steam and smoke" arose from the summit crater.† In the course of the preceding month, Judge Hitchcock, of Hilo, with others, visited this crater and found much escaping steam,

* Pacific Commercial Advertiser of May 9th, 1868. See also W. L. Green's Vestiges of a Molten Globe, pp. 294–303. Mr. Green does not intimate that Mr. Whitney's description is exaggerated.

† Coan, this Journal, xlix, 393, 1870, letter of Jan. 24, 1870.

but no visible fires. Slight shocks of earthquakes often occurred, sometimes one, two or three a day.

1870.—Mr. Severance (as I learn from Rev. E. P. Baker, of Hilo) was at the summit crater in 1870, and found no action there.

1872, *August* 10.—On the night of the 10th of August, says Mr. Coan,* "a lofty pillar of light," 2000 feet high—which means lighted vapors of this height—stood over the summit crater, with varying brilliancy, indicating active fires within. The crater was "in full blast on the 27th," and continued so into September. On the 23d of August a tidal wave was felt on the coast at Hilo, the waters during a calm rising four feet, and in a second wave, six minutes later, three feet, and diminishing for about fourteen oscillations. It may have been part of the Mt. Loa disturbance; but Kilauea also was unusually active over its interior. No earthquake is reported. The Pacific Commercial Advertiser of Sept. 21st† reports on an ascent to the summit made just before this date. Near the southwest corner of the crater there was a fountain of lava about 75 feet in diameter, playing, it is stated, to a height of 500 feet. The basin from which it rose covered about a third of the bottom, and was at the top of a low cone made by the falling lavas.

1873, *January 6th and 7th.*—On the 6th of January, the action at the summit, as seen from Hilo, was "marvelously brilliant," the lighted vapors visible at night rising thousands of feet above the summit.‡ There was evidence, apparently, of active ebullition or a playing fountain; and this conclusion is favored by the fact that the herdsmen of Reed and Richardson's ranch, at Ainapo, on the eastern slope (4200 feet above the sea), stated that the mountain was "constantly quivering, like a boiling pot." The action suddenly ceased, without any known outflow; the time of ending the display is not mentioned. Kilauea had been very active for months. No earthquake is spoken of, and no sympathy with Kilauea implied.

1873, 1874. *April* 20, 1873, *to autumn of* 1874.—The brilliant summit display of January was followed on April 20th, three months later, by a return to activity, or to a degree of activity that was visible from Hilo. Mr. Coan observes that the lofty columns of light above the summit at

* Coan, this Journal, III, iv, 406, 1872, letter of Aug. 27, 1872, and v, 476, 1873, letter of Feb. 14, 1873.

† This Journal, iv, 331, and 407, 408, 1872.

‡ Coan, this Journal, III, v, 476, 1873. letter of Feb. 14, 1873; vii, 516, 1874; xiv, 68, 1877. In the first of these notices, the date given is Jan. 27th; in the others, Jan. 6th and 7th.

night, and of clouds by day were proof of violent ebullition within the crater.

On the 6th of January, 1874, Mr. Coan writes* that, for nine months, the action within the great crater has not remitted. "The great marvel is its duration," without any outside results. There appears to have been a turn of special brilliancy in January. On the following October (the 6th), he says† the action has continued "for eighteen months, and the most of the time it has been violent. But of late it has become more quiet, and there is a prospect that it will soon cease." He adds, "we have had few earthquakes during the year, and these have been feeble." "Kilauea all this time was unusually active;" but no sympathy with Mt. Loa was observed.

1873, *June* 6.—It is of great importance to the history that we happen to have trustworthy reports with regard to the condition of the summit crater on one of the days during this era of prolonged activity. And as it was a day of feeble summit light as seen from below, it affords data for an estimate as to the condition during times of greater brilliancy. The explorer, Miss Bird,‡ was at the summit on the 6th of June, and describes well the condition of the crater. For the most part its floor was an area of solid black lava; but at one end (the southwest?) there was "a fountain of yellow fire" 150 feet broad, which played in several united but independent jets to a height of 150 to 300 feet. The party for the two days preceding had been under the impression that the fires had faded out; and yet this fire-fountain was all the time in action. When within two miles of the crater monitions of the activity were apparent in a distant vibrating roar; and on reaching the crater edge, the roar was like that of an ocean, rising and falling "like the thunder-music of windward Hawaii"—a comparison used also by Mr. Kinney in describing the eruption of 1852. (p. 19.) At night the lake was the most part at white heat, and its surface was agitated with waves of white hot lava about the fountain at the center. Through the rest of the vast crater the projecting ledges were thrown into bold relief by the reflected light, and by numerous dashes and lines of fire from apertures and crevices. Occasional detonations were heard, but no shakings except the tremors from the throw and fall of the lavas. At one time the jets, after long playing at a height of 300 feet, suddenly became quite low, and for a few seconds there were "cones of fire wallowing in a sea of light;" a description that not only reads well, but I feel sure is to the life, like the

* Coan, this Journal, III, vii, 516, 1874, letter of Jan. 6.

† Coan, ibid., viii, 467, 1874, letter of Oct. 6, 1874; and xiv, 68, 1877, letter of March 17, 1877.

‡ Six months in the Sandwich Islands, by Isabella L. Bird, London, 1876.

most of Miss Bird's pictures; then, "with a roar like the sound of gathering waters, nearly the whole surface of the lake was lifted up by the action of some powerful internal force, and its whole radiant mass rose three times in one glorious upward burst, to a height, as estimated by the surrounding cliffs, of 600 feet." "After this the fountain played as before." (p. 272). "In one place heavy white vapor blew off powerful jets from the edge of the lake and elsewhere, and there were frequent jets and ebullitions; but there was not a trace of vapor over the burning lake itself."

In "The Vestiges of the Molten Globe," (p. 166) Mr. W. L. Green, with whom Miss Bird made her ascent, gives confirmatory facts. He makes the height of the fountain generally 300 to 400 feet, as estimated from the known depth of the crater; and occasionally some spires shot up, he observes, to a greater altitude. He adds: "Among the varied forms of the fountain there were the low rounded dome, a spire at center, with a fountain either side in the form of a wheat sheaf, and one great wheat-sheaf." Besides a dull roar, there was "the metallic clink" from the fall of masses of lava of the fountain which were cooled in the air; these cooled fragments formed a light falling veil over the dazzling fountain, and descending into the lake outside of the jets, making a scum over its surface Only a light vapor was seen over the playing fountain.

Early in *August*, 1873, Dr. O. B. Adams ascended Mt. Loa, at a time when the light at the summit was unusually brilliant. He found the fountain playing, he says, to a height of 200 to 500 feet, and "assuming all the forms of a grand fountain of water."*

1875, *January*.—Mr W. L Green mentions the occurrence of summit action at this time for a month, in his tabular statement of eruptions, and says nothing of one in August of this year, to which date Mr. Coan refers the 1875 eruption. The report of the Challenger sustains Mr. Coan's statement, but does not positively set aside that of Mr. Green.

1875, *August*.—Mr. Coan says:† I think it was on the 11th of August that the summit crater was again in brilliant action. The action continued, as appeared in the view from Hilo, for one week, and without any observed evidence of an outflow.

In the first half of August, the day not stated, a party from the Challenger Expedition visited Kilauea. As reported in volume I of the Scientific Results of the Expedition, p. 766, "a globular cloud" was seen over the summit of Mt. Loa, which

* Hawaiian Gazette, Sept. 3, 1873.

† Coan, this Journ. xiv, 68, 1877, letter of March 17, 1877.

was "perpetually reformed by condensation," and had "a brilliant orange glow at night, looking as if a fire were raging in the distance."*

1876, *February* 13.—Another grand display from the summit crater, but of short duration. No outflow is reported.†

1877, *February* 14.—The display of light on the 14th, says Mr. Coan,‡ was "most glorious." The columns of illuminated steam rose "with fearful speed to a height of 14,000 to 17,000 feet, and then spread out into a vast fiery cloud, looking at night as if the heavens were on fire." The brilliancy continued only for ten days.

No outflow is positively known to have occurred, but it is probable that a submarine discharge took place off western Hawaii. The steamer brought passengers from Honolulu to visit the mountain, but returned as the fire had disappeared. But before the vessel was fairly out of sight of land, "a remarkable bubbling was seen in the sea about three miles south of Kealakekua, a mile from the shore," and steam and scoria were thrown up.

Mr. H. M. Whitney states that "blocks of lava two feet square came up from below, striking and jarring the boats"; and "nearly all the pieces on reaching the surface were red-hot;" "as soon as they became cold they sunk. This eruption took place on the 24th of February, the day the light disappeared from the summit.§

On the land new fissures were opened up the mountain that had a westward course toward the place of submarine disturbance. An earthquake is reported as having been felt in the fissured region, but not at Kealakekua. A heavy tidal or earthquake wave occurred about this time along the coast of Kona.

[1877, *May* 10*th*.—A destructive earthquake wave was felt at the Hawaiian Islands on May 10th, 1877, which rose at Hilo to a height of 36 feet. But it was of South American origin, where there were heavy earth-shocks, and not of Hawaiian.]

1880, *May* 1.—Early in the morning of May 1st, a light was seen at or near the summit, which soon after became intense so as to illuminate Hilo at night. It indicated violent activity, and led to an expectation of a great eruption. But clouds obscured the mountain for a few days, and when they disappeared, the light was gone.‖ On the 3d and 4th of May, flocks of Pele's hair and light particles of volcanic dust, drifted by the wind,

* See also Moseley's "Notes by a Naturalist of the Challenger," London, 1879, p. 500.

† Coan, this Journ., xiv, 68, 1877, letter of March 17, 1877. ‡ Ibid.

§ Hawaiian Gazette, Feb. 28, 1877.

‖ Coan, this Journ., III, xx, 7, letter of May 3–6, 1880.

fell over Hilo. According to reports from Puna and Kau, the action had not ceased by May 6th. Mr. Brigham reports* that his guide was at the summit at the time and saw boiling lava in the south crater; and that the top of the jets were visible to the native while he was lying down some distance from the brink; which would make the height of the jets, Mr. Brigham says, 1,000 feet. As the depth of the crater was not over 800 feet, his estimate is probably too high. Mr. Goodale, one of the party who ascended at that time, reported (as Mr. E. P. Baker writes me) that the lavas were thrown 60 or 80 feet above the brink of the crater on which the party were standing; and this confirms the report of the native guide and makes the height of the fountain nearly 900 feet.

1880, *July* 28.—At this date, Mr. W. T. Brigham found the crater without action as stated in his paper on page 35. The walls were much fissured about the southern pit; fresh-looking lavas covered the bottom; and a small area was seen on the west border of the pit, which was probably of recent ejection. Moreover, about the region around the crater there was much of the spongy scoria, some masses a foot in diameter.

1880, *Nov.* 5 to *Aug.* 10, 1881, nine months.—No "violent demonstrations or earthquake" announced the great eruption. The first light was visible in the evening of Friday from Waimea, and a few hours later in the night, from Hilo; and after midnight "the lavas could be distinctly seen leaping like a fountain into the air." The stream flowed northeastward, between those of 1852 and 1855, and by Sunday, the 7th, had reached the plain between Loa and Kea, a distance of 7 or 8 miles. From there it turned eastward toward Hilo.

A second stream, starting from near the source, flowed off to the southward toward Kilauea, which made in all a length of about ten miles.†

As observed by Judge Hitchcock‡ on the 10th or 11th, from the Kalaieha Hills at the south foot of Mt. Kea (see Plate I), the stream, along for 8 miles northward to the plain, was a continuous belt of fire, in steady flow, and also beyond this for some miles toward Hilo. The regular flow was interrupted half way from the plain to the source by the lavas rising into a huge dome, from which they flowed over like an immense fountain; but there was no fountain at the source.

In 4 months, on March 25, the stream was within 7 miles of

* Brigham, ibid., xxxvi, p. 33.

† Coan, Hitchcock, this Journal, III, xxi, 79, letter of Nov. 9–12, 1880; xxii, 227, 228, letter of June 28th and July 21st, 1881, and xxii, 322, letter of Aug. 24, 1881; Life in Hawaii, p. 325.

‡ This Journal, ibid., xxi, 79 and xxii, 226.

Hilo, or about 26 miles long; in 7⅝ months, June 28, within 5 miles; in 8½ months, July 18, about 2 miles; and August 10, 9 months after the outflow began, it stopped within three-fourths of a mile of Hilo. On June 30th, the movement, just beyond the Hilo tufa hills (the Halai Hills) was, as stated by Mr. D. H. Hitchcock, about 75 feet an hour.

In a communication to the Commercial Advertiser for November 20th,* the formation of the *aa* or clinker fields is described as follows by Judge Hitchcock. "The whole broad front of the then sluggish stream was a mass of solidified lava twelve to thirty feet in height, moving slowly along by breaking and bearing onward the crusted covering; along the whole line of its advance it was one crash of rolling, sliding, tumbling, red-hot rock, no liquid rock being in sight; there were no explosions, but a tremendous roaring, like ten thousand blast furnances all at work at once. The rough blocks lie piled together in the wildest confusion, many as large as ordinary houses. They [clinker-fields] form only when the movement is slow."

1882.—In this year (the month not stated) Capt. C. E. Dutton made his visit to the summit (Report, page 139). He found "no volcanic action whatever," "not even a wisp of steam issuing from any point;" and he makes no mention of any cinder cone at the bottom.

February, 1883.—Prof. C. H. Hitchcock was at the summit on the 15th, and found no activity. "A snow squall struck us, and *the entire floor of the crater was white with snow.*"

1885.—In April, 1885, Rev. E. P. Baker visited the crater and descended to its bottom. It was all quiet. In September and October of 1885, Rev. J. M. Alexander made a survey of the summit crater, for the Government survey, as described on a following page. At the summit around the crater, for a breadth of a fourth of a mile he observed many blocks from 50 pounds to a ton in weight of a "solid, flinty lava." The bottom of the crater was mainly flat with fresh lavas, and had two cones in it as represented on the map, the southwestern 140 feet high and smoking; steam was rising from numerous cracks but no fires were visible.

1887, *January and February.*—In December, 1886, earthquakes began to be frequent in southwestern Hawaii, and in increasing numbers and violence; by the 12th of January they averaged three a day. Between 2^h $12'$ A. M. of Jan. 17 and 4^h A. M. of the 18th, 314 shocks were counted in Kahuku by Mr. George Jones, 67 between the latter date and midnight, and 3 the following day. In Hilea, ten miles west, 618 were counted between 2 A. M. of the 16th and 7 P. M. of the 18th.

* Hitchcock, ibid., xxii, 228. Commercial Advertiser.

On the night of the 16th, with the sudden increase in the earthquakes, fires broke out at the summit near the small crater south of the summit crater (Pohaku o Hanalei, plate 1), and in a few hours disappeared. The height of the outbreak, according to Mr. E. P. Baker, was 11,500 feet. On the 18th, at 7 A. M., three hours after the cessation of the earthquakes, an outbreak took place in Kau, north of Kahuku. The lavas came from a fissure about 6,500 feet above the sea-level and 26 miles from the sea, and reached the sea at noon on the 19th, nearly four miles west of the flow of 1868. It extended the shore outward 300 to 500 feet without making a cinder cone on the sea-border. By noon of the 24th the flow had stopped, but the fires were still active along the stream.

At the outburst the lavas were thrown up into fountains; about 80 feet in diameter, and 80 to 100 in height. They were photographed; and two of the views, representing the same part of the stream and one fountain, are shown on plate III. Mr. Spencer, who visited the source on the 20th, states that there were fifteen fountains and that the highest was 200 feet; others make the height not over half this amount. The stream is stated to have flowed away bearing bowlders weighing tons, with explosions at intervals. The lava was mostly of the aa kind.

The earthquake in Kau threw down walls that had a northeast and southwest direction, the throw was to the southeast; and light wooden houses were moved 8 or 10 inches in the same direction or down the slope.

On February 20th, Mr. D. W. Hitchcock was at the summit and found vapors issuing from large fissures.

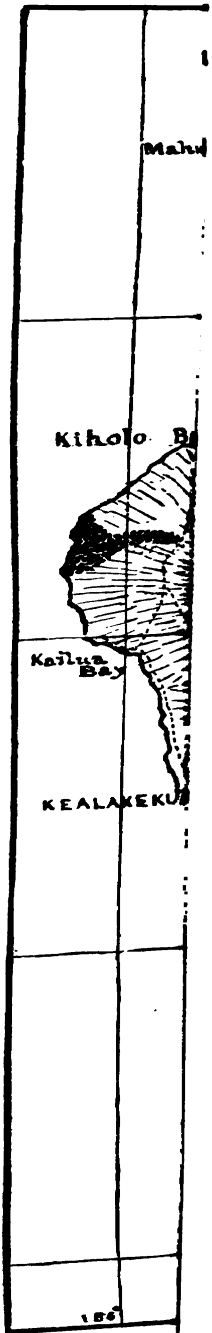
Kilauea was moderately active during the period of eruption, rather increasing in activity with its progress, but without evincing special disturbance or sympathy.*

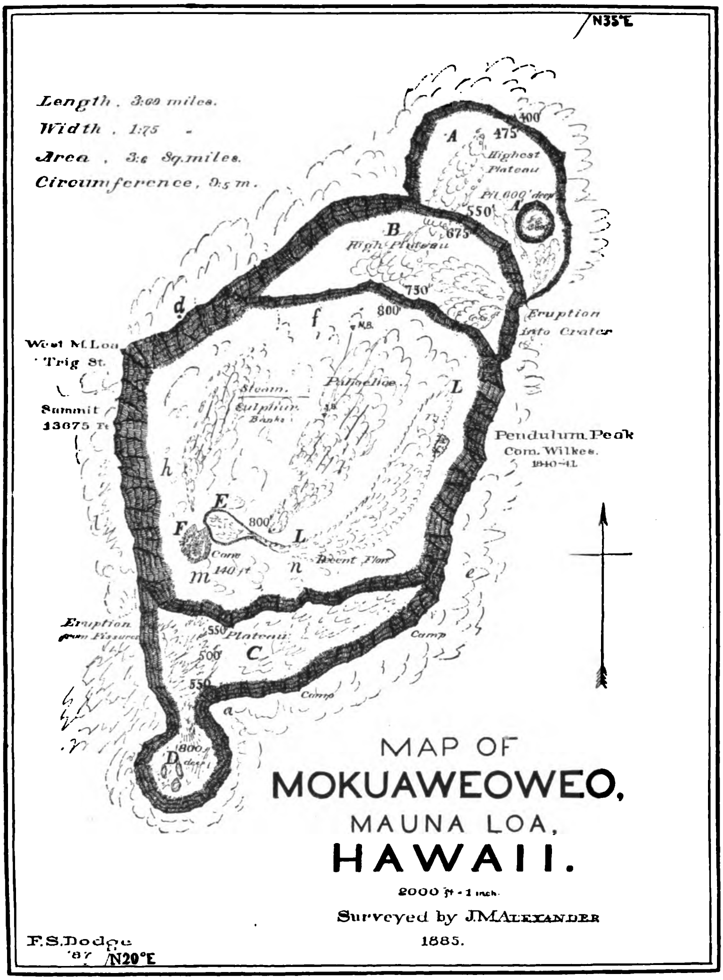
1887, *December* 29.—A letter from Mr. J. S. Emerson, dated Kohala, Hawaii, December 29th, states that the view of the summit of Loa from that place indicates activity in Mt. Loa. "Volumes of smoke and steam have been pouring out of the summit crater, but no glow or reflection of fire has been observed." "The summit is now heavily coated with snow." Another letter of April states that on March 29th, 1888, the signs of activity at the summit had disappeared; the exact time of their cessation was probably early in February."

[To be continued.]

* The above is from the Pacific Commercial Advertiser and Hawaiian Gazette of Honolulu; this Journal, xxxiii, 310, 1887.

Am. Jour.




N35°E
Length . 3.60 miles.
Width . 1.75
Area . 3.6 Sq. miles.
Circumference , 9.5 m.
A
400
475
Highest Plateau
Pit 600' deep
550
B
675
High Plateau
730
800
Eruption into Crater
d
f
West M. Loa Trig St.
Summit 13675 Ft
Steam. Sulphur Banks
Pahoehoe
L
Pendulum Peak Com. Wilkes. 1840-41.
h
E
F
800
L
Cone 140 ft
Recent Flow
m
n
e
Eruption from Fissure
550
Plateau
500
C
Camp
550
Camp
a
800 deep
D
MAP OF MOKUAWEOWEO, MAUNA LOA, HAWAII.
2000 ft = 1 inch.
Surveyed by J.M. ALEXANDER 1885.
F.S. Dodge '87
N20°E

Two views of a lava-fountain at the Eruption of January, 1887. From photographs.

[From the American Journal of Science, Vol. XXXVI, August, 1888.]

Art. XI.—*History of the Changes in the Mt. Loa Craters;* by James D. Dana. Part II, on Mokuaweoweo, or the Summit crater, continued.

[Continued from page 32.]

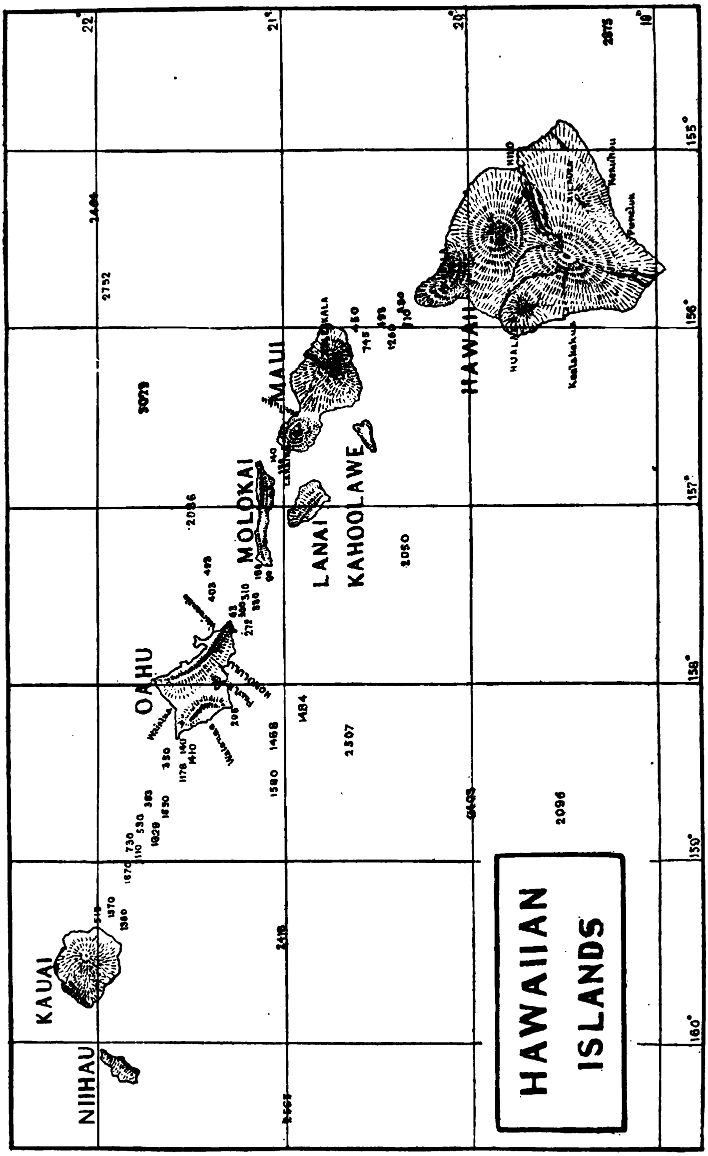
General Summary with Conclusions.

The subjects connected with Mount Loa and the summit crater considered in the following summary and conclusions are the following:

1. *The times and time-intervals of eruptions and of summit illuminations or activity*, with reference to (1) periodicity, (2) relations to seasons, (3) variations in activity since 1843, and (4), the changes in the depth of the crater.
2. *The ordinary activity within the summit crater.*
3. *Causes of the ordinary movements within the crater.*

Next follows Part III, treating of the causes of eruptions in Mt. Loa and Kilauea, and afterward, of the relations of the two volcanoes.

For the further illustration of the volcanoes the following map of the Hawaiian Islands is here introduced. Besides showing the forms of the islands, their relative positions and the two parallel lines between Oahu and Hawaii, it gives also the depths from the soundings of the Challenger and of vessels of the U. S. Navy, and others made with reference to telegraph-lines between the islands for which the map is indebted to the Hawaiian Government Survey.


HAWAIIAN ISLANDS
NIIHAU
KAUAI
OAHU
MOLOKAI
LANAI
KAHOOLAWE
MAUI
HAWAII
22°
21°
20°
19°
155°
156°
157°
158°
159°
160°

1. *Times and Time-intervals of Eruptions.*

1. *Question of Periodicity.*—Commencing with the eruption of 1832, there have been nine registered eruptions of Mt. Loa. Their times and heights of outflow, directions and lengths of stream, and relations to earthquakes, are stated in the following table:

	Reported Earthquakes.	Height of chief out-flow.	Direction and length of flow.
1. 1832: June 20, 2-3 weeks,.....	none.	Summit.	No outflow.
2. 1843: Jan. 9 to end Feb., 1½ mos.	none.	11,000.	N.N.W., 15 m.
3. 1851: Aug. 8, for 3 or 4 days,..	none.	12,900.	W., 10 m.
4. 1852: Feb. 17 into March, 20 d'ys	none.	little over 10,000	E., 20 m.
5. 1855: Aug. 11 to Nov., '56, 15 ms	none.	12,000.	E., 26 m.
6. 1859: Jan. 23 to Nov. 25, 10 mos.	none.	10,500.	N.W., 33 m.
7. 1868: March 27, 16 days,......	earthquakes	3,000.	S., 10–11 m.
8. 1880: Nov. 5 to Aug., '81, 9 mos.	none.	11,100.	E., 30 m.
9. 1887: Jan. 18, 10 days,........	earthquakes	5,600.	S. 14 m.

The intervals between these eruptions, reckoning (A) between their beginnings, and (B) between the end of each and the beginning of the following one, are:

	A.	B.
Between eruptions—1 and 2	10 years 8 mos.	10 years 7 mos.
2 and 3	8 " 7 "	8 " 5½ "
3 and 4	6⅛ "	6 "
4 and 5	3 " 6 "	3 " 5 "
5 and 6	3 " 5 "	2 " 2 "
6 and 7	9 " 2 "	8 " 4 "
7 and 8	12 " 7 "	12 " 7 "
8 and 9	6 " 2½ "	5 " 6 "

The eruptions above enumerated, that of 1832 perhaps excepted, were great eruptions; that is they had outside or subaerial outflows. But the history shows that at other times in the sixty-five years the summit of the mountain has been often brilliantly lighted, and surmounted with a column of clouds of great height, made apparently from the escaping vapors, which became a lofty column of light at night. These summit illuminations have been shown to be evidence (p. 27) not merely of action in or about the crater, but decisively of a boiling or fountain-like activity in the liquid lavas, if not also of out-flowing streams. The drifting of Pélé's hair on such occasions 35 miles to Hilo is as good testimony to the playing of jets or fountains as a note from an observer at the summit.

Moreover, we have learned from Kilauea that these times of brilliant action within the crater may be followed by subterranean or submarine discharges when not by subaerial; and therefore that they are not always merely the flaring up and

fading out of the crater-fires. They announce that *the top of the Mt. Loa column of liquid lavas is in the crater*, or has its maximum length, and is at serious work, even if no outbreak ensues.

The following table contains the times of these minor displays, as well as those of the admitted greater eruptions. In the table the latter are indicated by italics:

Dates.	Conditions at the Summit.
1. 1832. June 20.	Bright light at the summit, 2–3 weeks.
2. 1843. *Jan.* 9 *to late in Feb.; 1½ mos.*	Clouds; Jan. 10–17, bright light.
3. 1849. May, 2 to 3 weeks.	Brilliant light; just after activity in K.
4. 1851. *Aug.* 8; 3 *or* 4 *days.*	Bright light for 3 or 4 days.
5. 1852. *Feb.* 15 *to June; about* 4 *mos.*	Brilliant light for 24 hours.
6. 1855. *Aug.* 11 *to Nov.*, 1856; 15 *mos.*	Bright light at beginning.
7. 1859. *Jan.* 23 *to Nov.* 25; 10 *mos.*	Brilliant light at first.
8. 1865. Dec. 30; 4 mos.	Brilliant light for 4 mos., varying; at close, Kilauea increases its activity.
9. 1868. *Mar.* 27 *to Apr.* 12; *the flow* 4 *days.*	Bright light from March 27 to 30.
10. 1872. Aug. 10, into September.	Brilliant; a lava fountain of 500 feet; a tidal wave on the coast; K. very active.
11. 1873. Jan. 6, 7; 2 days.	Brilliant.
12. 1873. Apr. 20 to Oct., 1874; 18 mos.	Brilliant more or less for 18 mos.; in June and Aug., '73, a lava fountain, 300–600 feet.
13. 1875. Aug. 11; one week.	Brilliant.
14. 1876. Feb. 13; few days.	Brilliant.
15. 1877. Feb. 14; few days.	Brilliant; a submarine eruption.
16. 1880. May 1.	Brilliant; a lava fountain of 900 feet; Pélé's hair fell in Hilo.
17. 1880. *Nov.* 5 *to Aug.*, 1881; 9 *mos.*	Bright for a few days.
18. 1887. *Jan.* 16; *ten days.*	Bright for a few hours.
19. 1887. Nov. 25, into Feb.; 1 mth.	Vapors; no light seen.

The table contains the dates of ten periods of summit activity or illumination independent of the great eruptions; some short, but others prolonged for months, and varying greatly from time to time in brightness.

All these minor displays have taken place without initiating or announcing earthquakes.

It is obvious from the tables that the lengths of the intervals between the eruptions and the summit illuminations are too various, as far as now understood, to sustain the idea of periodicity.

2. *Relation to seasons.*—The evidence of a seasonal relation appears to be beyond question. Out of the whole number, 19, 5, counting in that of 1865, occurred in January, 3 in February, 4 in March, April and May, and 1 in June, making 13 in the first six months of the year. Of the remainder, 4 commenced in August and 2 in November. Thus 15 out of the 19 took place in the wetter season. Add to these facts those from Kilauea mentioned in volume xxxv, p. 16, where the months given are March?, January or June, May, May, Octo-

ber, April, April, March, and the number for the same months of the year becomes 20 or 21 out of 27.*

Full meteorological tables for a comparison of the months as to precipitation, both at the base and summit of the mountain, do not exist, and the discussion of this important question has, therefore, to be left unfinished.

I have received the following notes on the snows of Mt. Loa in a recent letter from Mr. J. S. Emerson of the Hawaiian Government Survey. "The snow-cap of Mt. Loa in general may be considered as making its first appearance in the early part of November, and as lasting until late into March. This is my impression from observations the past season, which I think has not been particularly exceptional. During the early part of November the snow-fall was quite light, and seemed to melt rapidly away at its lower edges. By the 25th there had been two heavy snow-storms covering the mountain top with a thick coat, which lasted all through the winter. The snows are usually the heaviest in the month of February, I think, though I did not see the mountain during that month this year. My last view of Mt. Loa was on March 29th, when I could just distinguish patches or streaks of snow on the more protected portions of the summit."

The *relation to barometric changes* is an important subject for future study, with respect to which we have now no knowledge. There are also variations in the amount of vapors over the active craters dependent on *hygrometric changes* to be investigated.

In view of the above facts it is probable that if there is any periodicity in eruptions, it is more or less dependent on meteorological cycles.

3. *Variations in activity since* 1843.—The copiousness of the subaerial discharges has diminished greatly since 1859. Before the end of that year, or in the 17 years from 1843 to 1860, five of the eight great eruptions had occurred; and of the three in the following 27 years, only one, that of 1880–81, was of great length.

The frequent occurrence of the brilliant summit displays during the twelve years preceding the middle of 1880 is another striking fact. Six cases are reported, and one was prolonged with small interruptions for eighteen months.

The first of these displays occurred nearly 4½ years after the eruption of 1868. But Mr. Coan, the mountain chronicler, was absent in this country during one year in the interval—from the spring of 1870 to that of 1871. After the summit-display of August, 1872, they came at short intervals, their

* This relation to the seasons, first recognized by Mr. Coan, is mentioned also by Mr. Green in his Vestiges etc., p. 332.

lengths from the end of one year to the beginning of another, reckoned in months, being 5, 3, 10, 6, 12. After February of 1877, there was the longer interval of 3½ years. Such short-period alternations seem to imply the recurrence after each of a subterranean discharge somewhere, if not a subaerial. The display of 1877 quite certainly ended in a submarine eruption, and probably that of 1872, (pp. 29, 26).

4. *The changes in depth of the summit-crater.*—The changes since the year 1834, when the crater was visited by Douglas, have diminished its depth by at least 400 feet, if we may trust—as we probably ought to do—his measurement "with a line and plummet," making it 1,270 feet. In 1840, Lieut. Eld, U. S. N., of the Wilkes Exploring Expedition, made the depth on the west side 784 feet (p. 16), and in 1885, J. M. Alexander, 800 feet, (plate II).

We know nothing as to variations in the level of the floor after and before an eruption, and nothing as to the down-plunges which have followed discharges. The terrace-levels situated at the north and south ends of the crater may mark high lava-levels just previous to some ancient eruption; but they antedate history; for Wilkes's map (p. 17) shows that they existed in 1840 very much as now. The map, Plate 2, by J. M. Alexander, which contains his "estimates" of the depths of the terraces or "plateaus" below the highest point or summit, makes the terrace at the south end on a level with the upper of the two at the north end, suggesting thus that the two may mark one of the high-lava levels of the crater. In addition, it places the bottom of the South Crater (D), and that of the pit in the upper north terrace or plateau (A′), at or below the level of the bottom of the central crater, favoring the view that all three parts of Mokuaweoweo are still in active connection; which view is sustained by the facts (1) that the fountain of May, 1880, was a South Crater fountain, and (2) that the pit A′ was formed since 1874, as it is not in Lydgate's map of the crater of that year.

2. *The Ordinary activity of the Mt. Loa crater.*

1. *General course of action.*—Although but few ascents to the summit-crater have been made since the first by Douglas in 1834, and only four of these found the crater in action, there are still facts enough for important conclusions. The *cycle of changes* has been, beyond doubt, the same essentially as in Kilauea; that is, when a discharge takes place: (1) the lava of the lava-column within the central conduit of the mountain falls to a level some distance below the crater (say one or more hundred feet), as a consequence of the loss by the out-

flow. Then begins (2) a rising of the lava of the column until it again shows part of its fiery top in the bottom of the crater engaged in its usual projectile work, and until finally it has reached a maximum height; and then follows (3) a new discharge, and another time of inactivity for the crater.

2. *The projectile action within the crater.*—Projectile action in the Mt. Loa crater is in strong contrast with that of Kilauea. Instead of the Kilauea feature of low jets suggesting ordinary ebullition, with only occasional throws to a height of 100 to 200 feet, the descriptions of the summit action tell solely of fountains of clustered jets 75 to 600 feet, and even 900 feet high, as if the height of the jets or the intensity of the action was proportional to the height of the lava-column. The four accounts of this activity, one in 1872, two in 1873, and one in 1880, are alike in this respect. One of the two in 1873 describes the crater when the summit-light appeared feeble from below, and the other when brilliant, and the former is scarcely less marvellous in its fountains. The evidence is almost conclusive that such fountains are of ordinary occurrence. This was the opinion of Mr. Coan; and Mr. W. L. Green, in view of his summit observations in 1873 (p. 28) and the reported facts of others, ascribes to all the periods of summit illumination "great fountains."

3. *Causes of the Ordinary movements within the Crater.*

1. *The rise of the lava in the conduit.*—The rise of the conduit lava may be safely attributed in part, probably a large part, as in Kilauea, to the quietly-acting ascensive force in the lava-column.

The other volcanic agency of greatest prominence, as admitted for other volcanoes, is that of the *rising*, *expanding* and *escaping* vapors. The vesiculating effects of the vapors as regards the Mt. Loa flow of 1880–81 have been already described (xxxv, 222): and it remains to consider—

2. *The cause of the high projectile action in the summit crater.*—Higher projectile action in Mt. Loa than in Kilauea through the escape of elastic vapors might come (1) from greater viscidity in the lava; or (2) from less specific gravity of the material; or (3) from a larger supply of vapors. The first of these causes cannot be the right one, for greater viscidity should lead to high cinder ejections; on the contrary, the lavas show that they are as mobile as the Kilauea lavas by the velocity of the lava streams and all the attending phenomena, and more by the free play of the fountains. The second is set aside by the near identity of the lavas in density:

that of the Mt. Loa flow of 1880–81 being 2·98; that of ordinary Kilauea lava, 2·97–3·05; an old lava, from Waldron's ledge, excessively chrysolitic, 3·15.

If neither of these explanations meets the case, we have only the third to appeal to—a greater volume of elastic vapors. It is, accordingly, probable that the cause which can produce *occasional* jets of 100 to 200 feet in Kilauea is capable of producing the *prevailing* high jets or fountains of the summit of Mt. Loa.

But why should the volume of vapors in the lava-column be greatest at the summit? The amount of work done there is ordinarily at least 100 to 1000 times greater than in Kilauea; for the jets are 5 to 10 times higher.

This difference in amount could not be a fact if the vapors within the slowly ascending lavas were from the profound depths that supply the lava, or even from depths much below the sea-level. For, under such circumstances, (1) the difference in the amounts carried up to the two craters would be small, since the rate of supply from below would be essentially uniform; and (2) the difference in the height of the columns would be more favorable to Kilauea, whose lava-column rises above tide level but 3700 feet, than to Mt. Loa 9000 feet higher. The area of the floor of Kilauea exceeds that of Mt. Loa.

But if freshwater from precipitation over the island supplies the vapors, then the difference in the heights of the conduit lava-columns is greatly in Mt. Loa's favor. A section of its lava column at the sea-level may receive moisture during the whole time of its rise to the summit, a distance 3·8 times that for Kilauea. The ratio 3·8 to 1 for the difference in supply of moisture to the columns would be too large on account of the less precipitation over the upper part of the mountain and the much less extent of surface in this part; but it may safely be put at 2 to 1, if not 2½ to 1. The ascensive movement in the Mt. Loa lava-column may be somewhat more rapid than in the shorter conduit of Kilauea, provided the hotter central portion derives any upward thrust from the pressure of the cooler lateral portion, (xxxiv, . . .); and this cause would diminish the difference between the two as to the supply of vapor received; yet not largely.

The fact here apparently established—that only through waters from the island-precipitation could Mt. Loa get its larger supply—affords new evidence that *the inland waters are the chief source of the vapors concerned in Hawaiian volcanic action.*

Is there any other source of the Projectile action? The lava-fountains of the summit-crater are so marvelous in size considering the density of the lavas, so near the incredible, that we naturally seek for other possible explanations.

Hydrostatic pressure is out of consideration, inasmuch as the fountains are at the summit of the dome and at times throw their jets 50 to 100 feet above the mountain's top—over 14,000 feet above the sea-level.

Another source of projectile action has been suggested by Mr. Green, as briefly mentioned on a preceding page (xxxv, 216). In opposition to other writers on volcanoes, he sets aside the idea that vapor of water is concerned effectually in the projectile action even of Kilauea. The feeble amount of vapors observed by him over the fountain of the summit-crater in 1873, and the general absence of vapors from the flowing lava-streams of 1859 and 1880–81, besides other similar facts, have led him to his position on this point. He recognizes the fact* that great heaps and columns of clouds form over an active crater, and rise at times to a height of many thousands of feet; but accounts for these on the assumption that the heated current ascending from the active crater derives rapid accessions of air from either side, and this air, by being carried up to cold heights, yields the moisture by condensation, and so forms the column of clouds. Further, he finds a cause of some projectile action for the Kilauea lava-lakes and others in atmospheric air carried down by the descending lavas of the jets into the lava-lakes—as the crests of waves carry down air into the sea; and for the rest of it, or that producing the crater-fountains like those of Mt. Loa, he holds that the ascensive action in the conduit, after a time of quiet, suddenly overcomes resistances or stoppages that have come to exist in the conduit at depths below, and, as a consequence, the lavas, suddenly released, are thrown up in fountains, like the jets of mineral oil from an artesian boring.

I have already met part of the argument as to the absence of vapors of water, in my remarks on vesiculation, by showing (1) how extremely little moisture is needed to produce vesiculation (xxxv, 226), and (2) how much moisture hot air will dissolve and make invisible. It has also been stated (3) that if a Mt. Loa lava-stream has but a single fountain-head, as is generally supposed, though not proved, nearly all the vesiculation must occur at the source, so that for this reason and the heated air above it, the lava-stream should be vaporless, or appear so, except where there are fissures below for additional supply.†

Further (4), direct observation proves that the vapors come up out of the crater. They often rise directly from the

* Vestiges of the Molten Globe, pp. 75, 162–167, 175, 272–278, 309, 314.

† Mr. Green states, as an exceptional case, that at one place on the Mt. Loa flow of 1880–81, the lavas spread into a large lake, and vapors rose from it in great amount. This is good evidence of the existence there of a local supply of lavas through a fissure.

orifice of the crater, too low down for the air-current to have got into action; and in such cases there is an obvious source for the condensed moisture, and that is, the liquid lavas of the crater. Mr. Green expresses the fact well in the words (p. 169) "There is very often a large quantity of smoke seen to arise from the orifices of eruption, and this often spreads out in the higher regions of the atmosphere. There was a column, perhaps 500 feet wide and 10,000 high, arising from the orifice of 1859 when we pitched our tent along side it," at a point on the mountain 10,500 feet above the sea-level.

Further (5), the feeble amount of vapor observed by him in 1873 over the fountain in the summit-crater, so unlike what had existed a few days before, may have its explanation in the dryness of the atmosphere at the time. The air is generally dry at the summit, but must have its phases of unusual dryness, during which an unusual amount of escaping moisture would, for this reason, become invisible.

(7) The summit fountain is a combination of jets, each of which must have had its initiating projectile act; and it continues for weeks and months; and this is at variance with the evidence from Kilauea, which makes the ascensive action very gradually and quietly lifting, instead of projectile.

Finally (8) the cold atmospheric air carried down into a lava-lake by the jets could generate very little projectile power. The air, on entering the lavas, would encounter a temperature near 2000° F. if not beyond it, and hence the expansion would cause expulsion, or a speedy escape, in spite of any currents or intestine movements that might exist in the boiling cauldron.

For these reasons we may conclude that the old and generally accepted explanation which attributes the projectile action chiefly to water-vapor is not seriously invalidated by the ingenious suggestions brought forward by Mr. Green.

Part III.—ERUPTIONS OF KILAUEA AND MT. LOA.

In the following pages the subjects considered are: I. The characteristics and causes of eruptions; II. Metamorphism under volcanic action; III. The form of Mt. Loa as a result of its eruptions; IV. The relations of Kilauea to Mt. Loa; V. General volcanic phenomena.

Under the head of Eruptions, the principal topics are: the kinds; the places of outbreak; the causes of eruptions; the characters of the lava streams; the positions and origin of the subordinate lateral cones.

I. Characteristics and Causes of Eruptions.

Eruptions are of two kinds: (1) *Non-explosive eruptions*, or quiet outflows, seismically attended or not; and (2) *Explosive eruptions*, or catastrophic upthrows. Both kinds are exemplified in Hawaiian volcanic history. There are also (3) combinations of the two kinds in volcanic regions.

1. ORDINARY OR NON-EXPLOSIVE ERUPTIONS.

Kilauea and Mt. Loa are alike, as has been shown, in (1) their mode of work; (2) the southward position, in the crater, of the point of greatest activity; and (3) the general features of their eruptions. But in amount of eruptive work the summit crater is far ahead of Kilauea, and, in fact, it leads the world. Kilauea has had but one subaerial outflow of any magnitude in the last fifty years, and that only twelve miles long. Mt. Loa, on the contrary, although nearly 13,000 feet up to the bottom of the crater, has had in the same time only one of its eight less than twelve miles long, and several between twenty and thirty-five; and it has reached its height without a loss of eruptive power. It is reasonable, therefore, that Mt. Loa should have most instruction to give about outflows.

1. *Heights and positions of the places of outbreak.*

1. *The Heights.*—The place of outbreak of a Mt. Loa eruption may have any height from the summit to levels far below the sea-level; and this "far below" may be, as the map on p. 82 shows, 17,250 feet down before reaching the actual foot of the eastern slope. The heights of known occurrence are mentioned in the table on p. 83. The completion of the topographical survey of Hawaii, now in progress under the government, will before long give more correct figures. The height of the source of the one Kilauea outflow, that of 1840, or rather of the spot where it appears to begin, is 1244 feet (Wilkes).

In each of the cases of eruption, fractures were made near the summit which extended down the mountain, with only small discharges along them when any, to the place of chief outflow. In some cases, fissures have opened on the brink of the crater and let out lavas; but all the large outflows of modern time have come from points a thousand feet or more below the summit.

2. *Relations between the positions of the places of outbreak and the diameters of the craters.*—The course of the northern half of the longer diameter of the summit crater is about N. 35° E., and that of the southern half, about N. 20° E. or

S. 20° W., as marked on the upper and lower margin of Plate II. Four of the largest lava-streams of Mt. Loa, those of 1843, 1852, 1855 and 1880, and two others to the south, those of 1868 and 1887, have their places of outbreak nearly in the line of the respective halves of *the longer diameter*. Again, three of the eruptions, those of 1851, 1859 and 1877, broke out on the west side of the summit, nearly in the line of *the shorter diameter*, or between the summit and Hualalai.

There is here probable evidence of a dependence of the eruptions to some extent on the two great fissure-lines upon or about which the mountain's foundations were laid.

The direction of the longer diameter of Kilauea is about N. 50° E.–S. 50° W. The chief course of eruptions, as on Mt. Loa, is marked by a line of fissures and ejections running west-southwestward in the direction of the longer diameter. But the large outflow of 1840, and the fissures leading to it, instead of pointing toward the crater, have a course nearly *parallel* to the longer diameter, but fifteen miles south of the Kilauea line. This is seen on the map, page 82, but better on Plate I, the stream being the one near the east cape.

2. *Causes of Eruptions.*

1. *State of readiness for an Eruption.*—The *ordinary quiet* work of the craters has been shown to be carried on by—

(1) The ascensive force of the conduit lavas; this force producing (1) a slow rise in the liquid rock from depths below; and (2) a raising of the crater's bottom.

(2) The elastic force of rising, expanding and escaping vapors; producing jets and fountains in the lava-lakes; overflows or ejections spreading the lavas over the crater's bottom; vesiculation of the lava and consequent increase of its bulk.

Other causes have been mentioned as occasionally in action (xxxv, 228), but as not essential to the chief results.

After a season of this ordinary activity, with more or less gradual increase of intensity, a state of readiness for an eruption and its determining conditions have been reached. This has happened when the lava has risen, through these agencies, to what might be called *high-lava mark;* a level some hundreds of feet above low-lava mark or the low level occasioned by the preceding discharge.

2. *Action needed for an Eruption.*—After this preparation nothing is needed for an eruption but an agency of sufficient force to break the lava-conduit; for if broken seriously the lava will run out, and therein is an eruption or discharge.

Neither of the agencies carrying on the ordinary quiet work of the volcano has shown itself capable, during historic time, that is, since 1822, of breaking the lava-conduit for a discharge.

The escaping vapors have spent their force mostly in making jets and fountains and feeble outflows; and still more quiet has been the work of the ascensive force. Eruptions have been a sequel to years of this quiet work, but not a direct effect of the action.

3. *Agency of Earthquakes.*—Earthquakes have often been considered an effective agent in eruptions. But during the past sixty-five years only two of the eruptions of Mt. Loa and one of Kilauea have been introduced or attended by noticeable earthquakes. The eruptive agent in both volcanoes has in general worked quietly, "as quietly as the moon rises," says one writer, without much exaggeration. The star-like light on Mt. Loa has been followed soon by a stronger glow; and, accompanying this, a rising of clouds into heaps and lofty columns. After a day or two or three, the summit-light having disappeared, the flow has begun one, two, or three thousand feet below the top; and a line of light has then slowly lengthened down the mountain for twenty or thirty miles; and all this, quietly. It is the grandest of volcanic work with the least possible display of force.

The facts connected with the two eruptions of Mt. Loa and one of Kilauea, that were attended by earthquakes, merit special review in this place because they teach what earthquakes may do, and by what means. The three occurred in the years 1868 and 1887.

On a Friday in 1868, March 27 (p. 24 and xxxiv, 91), a light was seen on the mountain and feeble earthshocks occurred. Only slight eruptions followed. Then, in accordance with the ordinary rule, these first fires at the summit disappeared. But the earthquakes increased in violence—not about the summit, but far to the southward, within the lower three or four thousand feet of the mountain. And they continued increasing until that "terrible shock" of Thursday, April 2d. Five days later, April 7th, the lava burst out from an opened fissure at a point, 23 *miles distant from the summit* and only 10 or 11 from the sea-coast.

It is here manifest that the earthquakes had nothing to do with *preparing* for the eruption; they were too late for this. It is possible that the first break near the summit anticipated the first earthshock But below, in the region of most violent disturbance, greater fissures were opened, the profoundest probably at the very time of that "terrible shock;" and as soon after as the subterranean passage could be made—about five days—the lava from the broken lava-conduit or reservoir made its appearance at the surface and hurried down the mountain to the sea. But at the sea-border and elsewhere the fissures were probably ahead of the lava, according to Professor

C. H. Hitchcock, and gave it exit nearly all the way, occasioning their rapid progress seaward.

Here then it is clear what the earthquakes did to produce the eruption. They, or the cause generating them, broke a hole into the conduit, and the lava escaped. The lava of the conduit was not thrown into commotion or projected to great altitudes at the summit; instead, it sank out of sight, following the rent to the surface far down the mountain. These events were repeated almost precisely in the Mt. Loa eruption of 1887. The locus of the outflow and of the earthquakes in both cases was far south in southern Hawaii, and the two streams followed near and parallel lines; the chief difference between them was in the higher outlet in 1887 by 2500 or 3000 feet (see map, page 82).

The earthquake eruption of Kilauea was coincident with the first of the two Mt. Loa eruptions in April, 1868. The earthquakes were the same identical earthquakes; and that "terrible shock" of April 2d was for each the special discharging agent. Immediately after the shock the fires of Kilauea, before unusually active,* commenced to decline; by night of that Thursday, all the burning cones, by night of Saturday all the smaller lava-lakes, and by Sunday night, the great South Lake, had become extinct. And then, the lavas having run off, half the floor of the crater sunk down 300 feet.

A genetic connection between the earthquake disturbance and the eruption cannot be doubted. The earthquakes came after the crater had reached a state of unusual activity, and hence could have taken no part in the preparation. They simply discharged the lava by breaking the conduit that held it.

Moreover, the earthquakes which thus emptied Kilauea were of Mt. Loa origin; they had their center thirty miles or more west of Kilauea, and were made through the Mt. Loa fires. It is a case, therefore, of one mountain-volcano accidentally discharging the conduit-lava of another. The work was simply a fracturing of the mountain in different directions; for the island was violently shaken from the west side to Hilo on the east coast; and, in the general fracturing, the two volcanic conduits were broken at once, an accident not likely to often happen.

It is also to be noted that *the earthquakes were of local or volcanic origin.* This is established by the fact that only two of the heaviest shocks reached westward to Honolulu on Oahu

* Dr. Hillebrand states that for two months previous to the eruption there were eight lava-lakes in the bottom; and until March 17th, a very active blow-hole in the northwest corner, where "large masses of vapor were thrown off as from a steam engine" on Thursday, April 2d, after the earthquake, there were fearful detonations in the crater, and portions of the wall tumbled in; and then began the decline.

(p. 24); and these so feebly that they did not make themselves generally felt in that city (see map, p. 82). The depth of the oceanic depression between Hawaii and Oahu, which is only 500 fathoms where least (between Hawaii and Maui), was sufficient to stop off the vibrations. Further as in the Mt. Loa eruptions, no increase of projectile action was occasioned in the crater by the earthquake disturbance; the lavas simply, in the quietest way, ran off, leaving the crater empty, still and dark.

A mountain having within it two great regions of liquid lava thousands of feet in height, each at a temperature above 2000° F., and with subterranean waters abundant, at least through the lower two-thirds of the altitude, is well fitted for the production of eruptive crises; and it is remarkable that the eruptions of 1868 and 1887 are the only ones seismically occasioned, or attended, in the past 65 years; and, further, that in these eruptions, although among the most violent on record, the craters were wholly free from explosive action.

The violent earthquakes of 1868 and 1887 accomplished nothing so far as the eruptions were concerned that is not effected on Hawaii in four eruptions out of five without them. The greatest of the eruptions have had no such aid. In the preparation for a discharge, the mountain has reached a dangerous state, because of the elongation upward of the fire column; then the fracturing agency has done its work; earthquakes are only a possible incident. With or without them, the conditions and results are the same; for vibrations necessarily attend fracturing, and earthquakes are simply the stronger or perceptible earthshocks.

4. *The rupturing and ejecting forces.*—The chief cause of the rupturing is no doubt the elastic force of suddenly generated vapor. So far this is an accepted explanation. As to the conditions under which this vapor is generated, there is not so general agreement.

The facts show, *first*, that on Hawaii the vapors are not suddenly generated *within* the conduit; for in the event, the lavas slink away from the crater, instead of dashing up wildly to great heights. If not generated *within*, it must be *without*, and the most probable region is that of the hot exterior of the conduit, or the hot rocks encasing the liquid column, or else fissures or local fire-places adjoining it. In this view the fracturing depends on the sudden access of subterranean waters to this outside region of great heat.

Secondly, the evidence proves that the force makes a fissure or fissures for the discharge of the lava without giving the waters entrance into the conduit. The pressure of the elastic vapor expends itself in breaking the sides of the mountain, and

only under the most extraordinary circumstances is the water forced into the lava-column. The earthquakes of 1868 were an exhibition of the power generated; and hardly less so is the noiseless fracturing for the greatest of eruptions.

Some erupting action comes from hydrostatic pressure. But the fact that the fissures first open quite near the summit of Mt. Loa is evidence that pressure from this source is the least efficient agent.

Why southwestern Hawaii should be especially liable to violent earthshocks in connection with its outflows is not wholly clear. But there are three significant facts bearing on the question.

(1) The southern half of the longer diameter of the Mt. Loa crater, and fissures from it down the mountain, point directly to the place of outbreaks of 1868 and 1887, the probable localities of the earthquake epicentra of those years.

(2) The longer diameter of Kilauea, with a long line of fissures, having the trend S. 52° W., points nearly to the same region of outbreak; so that the *two diametral lines, the Mt. Loa and the Kilauea, there intersect.* (See map, p. 82 and Plate I.)

(3) These lines have long been common directions of fractures and eruptions, as shown by the old lavas of the surface as well as by existing lines of fractures.

This divergence between the courses of the longer diameters of the craters of Mt. Loa and Kilauea comes up again for consideration in the remarks on the relations of the two volcanoes.

In the eruptions the *ejecting* force may be feeble or null; for the lava may flow out, when the source favors it, simply through gravity; but, in general, ejection is pushed forward, (1) by the elastic vapors within the lava-column; by vapors generated outside, like those producing eruptions; and by hydrostatic pressure.

The first of these causes is the source of the high fountains in the summit crater; and the summit effects indicate that it should have great propelling power at places of outflow. The fountains at the outflows have hitherto been attributed to hydrostatic pressure; but the two causes must here act together, and it is impossible to say from present knowledge which preponderates.

Fountains attended the outbreak at the eruptions of 1852, 1859, 1868 and 1887 (pp. 19, 22, 24, 32,); and it is probably that examination at other times would have added one or two to the list. The lengths of the lava-column (A) above the place of outbreak at these eruptions, and (B) the reported heights of the fountains in feet, are as follows:

	1852	1859	1868	1887
A	2500	3000	10,000	7000
B	200–700	300–400	200—; 600?	200? 80.

Owing to the height of the column above the level of the outlet in 1868, 10,000 feet, the hydrostatic pressure should then have been greatest; the force from the vapors in the lava-column, least; and the friction in the very long passage-way from the broken conduit, the most obstructing.

The second source of ejecting and fracturing pressure mentioned above is the probable origin of the fractures which sometimes cut through the walls of a crater to the summit; and if the vapors producing the pressure are generated over a source of liquid lava, the fissures would necessarily become injected with lava which might flow out above in a stream. Cases of this kind about Kilauea occurred at the eruptions of 1832 and 1868, (xxxiii, 445, xxxiv, 92); and Mr. W. T. Brigham and Rev. J. M. Alexander mention others, of uncertain date, about the summit crater.

Mr. Alexander speaks of a "cataract of lava" descending the walls into the crater from the summit; and farther south, of two other similar cataracts; and at the summit he found the deep fissure from which the cataracts had been supplied with lava, and ascertained that it had also poured out an immense stream northward upon the first plateau and thence southward into the central crater. "On the southwest side of the crater there had been another eruption from fissures that were still smoking, and the eruption had sent a great stream southward toward Kahuku and had also poured cataracts into the south crater from all sides." "The flows were from some of the highest parts of the brim;" and "from the brink there had been large flows down the mountains." "These outbreaks from fissures around the rim indicate that the lava has rather poured into the crater than out of it; and also that it has flowed from such fissures in vast streams down the mountain side." These cases perhaps date from the eruption of 1880, the last that preceded Mr. Alexander's investigation of the crater.

Such events if attending an eruption belong to its very beginning before the lava is drawn off from the crater. They may occur at other times; that they do so is not yet certain, except in a small way within Kilauea, about the lava-lakes. (xxxv, 228).

3. *The Outflows and the circumstances attending them.*

1. *The source.*—An outflow of lava may commence as a stream or as a fountain. In either case, the pent-up vapors of the lava-column make their forcible escape with the lava; and a cone

of solidifided lava more or less scoriaceous is usually formed about the vent by the pericentric action. These cones are mentioned in the descriptions of all the outbreaks, not excepting that of 1880, which was visited by Rev. E. P. Baker. Large deposits of cinders, or a light scoria, are sometimes distributed over the adjoining region, and Pélé's hair is also a common product; the former where the lava is thrown up in fountains and partially cools exteriorly as it falls (p. 28), and the latter from the action of either the fountains or the low jets (xxxv, 221).

The summit crater of Mt. Loa, unlike Kilauea, is often left, after an eruption, with one or more cinder-cones on the bottom; the larger of them usually in the southern portion of the crater. They are probably made from the lavas as the heat declines with the first commencing movements of an eruption.

2. *Rate of flow.*—The great flow of 1852, so grand in its fountains and twenty miles long, was finished in twenty days; this gives, for its mean rate of progress, a mile a day. The flow of 1859, thirty-three miles long, occupied only eight days, which corresponds to a rate of four miles a day on a mean slope of 1 foot in 15. The thirty miles to Hilo in the stream of 1880–81 took nine months; and the mean slope was 1 foot in 13 or about 5 degrees.

The general conditions in the flow of a great stream, its obstructions and modes of overcoming them, are well described by Mr. Coan (p. 20). As to actual *rate* of flow, we want more precise facts. It is difficult to reconcile the facts stated on these points; and especially the various velocities attributed to the different portions of a flowing stream, for example: the reported rate in one of the tunnels of "40 miles an hour" with a rate for the front of the flow of "one mile a week." The difficulty is still great if we suppose the 40 to be only 10, and whatever the obstructions along the front. The conditions are those of a discharging faucet, and the flow below is that of the liquid after its escape spreading widely over a rough surface.

The many openings through the crust of a stream into the tunnels which give out vapors, and often have the shape of jagged cones, suggest the possibility that a fissure may exist beneath in these and similar places for the discharge of lava and vapors. But the idea that such fissures generally underlie a lava stream (which I formerly thought probable) is opposed by Mr. Coan; and there are not facts to sustain it except for the Mt. Loa stream of 1868 and the Kilauea for 1840.

The tunnels of a stream, made by a crusting of the surface while the lava continues flowing beneath, have a smooth, somewhat glassy or enamelled interior, with horizontal flutings and mouldings which were made by the moving lava. In a tunnel

of the stream of 1880–81, near Hilo, which I visited under the guidance of Rev. E. P. Baker, one of the lines of mouldings had the form and position along the side of a solid handsomely modeled bench, indicating that the lava had encountered an outside obstacle in a projecting angle of cooled rock. This tunnel had a varying height of 4 to 8 feet and a general width of about 30 feet, but also some branchings and lateral expansions of large extent. The roof was two to six feet thick. The smoothness of the interior is favorable to a high velocity. The small capacity of the one entered near Hilo suggested the following queries: How much of the lava of a stream a mile wide runs in tunnels? Does the little width of the tunnel, and thereby of the supply stream, account for the difference of velocity in the tunnels and at the front? if so, the exit should be as free as that from a faucet, or the arrangements would not work. How many such tunnels exist side by side? Does a single tunnel continue on for 20 or 30 miles as an uninterrupted lava duct? We should infer that for a large stream the system of tunnels would become a very complicated one.

Whatever doubts exist as to rate of flow, there is none as to the extreme liquidity of the Mt. Loa lava, and its equalling if not exceeding that of Kilauea.

3. *The amount of Lava discharged.*—There are no data as regards the breadth or the depth of the streams, for a satisfactory calculation of the amount discharged. The depths might at many points be ascertained from the holes left by burnt trunks of trees. We can now only make a supposition.

The flow of 1852 was 20 miles long. If we suppose the mean depth of the stream to be 20 feet, and the mean width, 5000 feet, the amount of lava it contains would be 10,560,000,000 cubic feet. Supposing the lava-column to have the mean diameter of the central part of the summit crater, 9000 feet, it would contain, down to a depth of 2500 feet, (the place of discharge for that eruption) nearly 160,000,000,000 cubic feet of lava, or fifteen times as much as was discharged. Accordingly, the discharge, if the above figures represent the whole amount, would have drawn off less than 200 feet in depth from the lava conduit; and a rise of 200 feet again would have made the mountain ready for another discharge. The calculation is suggestive, though otherwise of little value. In addition to the other uncertainties we know nothing as to how much of a discharge passes off into subterranean cavities; which may be very large, for the great eruption of Kilauea in 1832 has little to show over the surface of the island.

Whatever the amount of lava or of height that is lost by the lava-column at an eruption, it has taken, as has been shown, but a very short time in several cases, to fill up again for a new dis-

charge. I repeat here that after the eruption of 1852, which produced a stream 20 miles long, had closed, the lofty volcano was ready in only 3½ years for a 26-mile flow, that of 1855; and in 3½ years more, for another still longer, that of 1859, 33 miles in length of stream: which is brisk work for the great old mountain. According to these facts the lava-column had risen, after the eruptions, at the rate of at least 100 feet a year so as to reach again the bottom of the crater and be ready for another discharge.

4. *Kinds of Lava-Streams. Pahoehoe and aa.*—The ordinary smooth-surfaced lava-stream, the pahoehoe, needs here no further description. The *aa*-stream is less often seen in process of formation and is more difficult to understand. With reference to an explanation of its origin, I repeat here from volume xxxiv the characteristics of the typical kind (not of the thinner streams that approximate to the pahoehoe), and reproduce also the sketch of a portion of one to aid the conception of its roughness; the reader's conception of it will be feeble at the best if he has not had a view of chaos already.

a. The characters of the cooled aa-stream: (1) a mass of rough blocks one foot and less to 1000 cubic feet in size, loosely piled together to a height of twenty to forty feet above the general level; (2) the blocks bristled with points but not scoriaceous, and less vesiculate than most of the pahoehoe;

Portion of an aa lava-stream.

(3) the material rather brittle, and consequently, when made up of small blocks or pieces easily broken down to a flat surface for the site of a house; (4) often aa in one part, and pahoehoe for the rest—either the chief part; (5) from one outbreak a pahoehoe-stream in one direction and an aa-stream in another.

b. The constitution and condition when in motion: (1) a mass of rough blocks outside, precisely like the cooled; (2) the motion extremely slow, indicating a semifluid condition beneath; (3) a red heat often in front among the blocks; (4)

fused rock seldom exuding; (5) the blocks of the upper part of the front, as the stream creeps on, keep tumbling down the high slope, owing to retardation at bottom from friction, and thus a rolling action in the front part.

The aa-field, owing to its crevices and shaded recesses, retains moisture, and decomposition at surface early commences, which favors germination of seeds; and often the stream, as I am informed by Mr. Baker, becomes forest-covered when the pahoehoe alongside remains bare.

One of the best published descriptions of an aa-flow is that of Judge Hitchcock (p. 31) which says: "Along the whole line of the advance, the stream, twelve to thirty-five feet in height, was one crash of rolling, sliding, tumbling, red-hot rock, no liquid rock being in sight; with no explosions, but a tremendous roaring like ten thousand blast furnaces all at work at once." Mr. Baker writes (letter of February, 1888): "I have stood by a wholly molten stream of lava which miles below was cooling into aa."

Under the restrictions of such facts the aa cannot be explained by referring it to simply a partial cooling of a stream and then a breaking up of the crust on a new accession of flowing lava—a common explanation; for there is no evidence of a crust from surface-cooling analogous to that of pahoehoe. It is not dependent on the mineral constitution of the lava; for one and the same stream may take either condition; and adjoining fields near Punaluu are at opposite extremes as to the amount of chrysolite.

The *first* conclusion we may draw, in view of the facts, and especially the abrupt transitions from aa to pahoehoe and the reverse in the flowing stream, and the independence of kind of lava, is that the difference must be connected with some condition in the region flowed over; and, the *second*, that where the transition from one kind of stream to the other occurs, the conditions must be such as will allow of extreme liquidity in one part (the pahoehoe), and occasion imperfect liquidity or a pasty state in the other (the aa).

It follows also from the size and rough character of the blocks of lava, *thirdly*, that in an aa stream the lava must have been subjected to some deeply-acting cooling agency to have made a crust thick enough for blocks 10 to 20 feet and more in dimensions—far thicker than the crust over the tunnels in a pahoehoe stream. *Fourthly*, that the cooling was not from above downward, as in the pahoehoe, for there are no remains of a crust in the true aa field, but largely from below upward; and thence comes the absence of a crust and of the usual amount of vesiculation.

These four conclusions appear to lead directly to a *fifth:*

that the region flowed over and making aa was one having more or less of subterranean moisture, since only moisture could produce the partial cooling required; not a superficial stream of water that the lava could evaporate and so put out of its way, but deeper and more widely spread moisture; and not too much for the quiet work of molecular imbibition and thereby of cooling and fracturing, with sometimes a "tremendous roaring like ten thousand blast furnaces." The aa near Hilo, of which I have spoken, was over a valley depression beneath which such an amount of moisture may well have existed. Another was along the foot of the meeting slopes of Mt. Loa and Kilauea, west-southwest of Kilauea. But my own observations were too brief to authorize a positive opinion as to the influence of the form of the surface in these cases; and in others, according to the descriptions, the surface covered by the aa is not always depressed.

There must be more or less moisture in the dark recesses of Mt. Loa. The cold summit will find enough in the air to condense at most seasons. And the percolating rains must keep the recesses damp and even make standing water wherever the rocky layers favor it. With subterranean moisture a hundred yards more or less beneath the broad lava-bed, the generated vapors would ascend into and through the liquid mass, cooling it thus from below. yet not so much the hotter bottom which receives new supplies of lava, as the portion above. The part solidified would become shattered or broken up by the tearing steam and by contraction from cooling; and, at the same time, the flow at bottom would displace and tumble together the great and small masses, giving the pile height because of the jagged forms of the blocks and the cavernous recesses left among them. This view appears to meet the demands of the facts I have observed, and all others so far as they have been published. But I present it only as a suggestion.

On this view an aa stream is literally an arate or ploughed up lava-stream; a stream ploughed up from near its bottom, so that, although vesiculated, the surface vesiculation fails, as was well shown in the stream of 1880–81 near Hilo, and in all the other cases I examined.

Dome-shaped bulges in a cooled lava stream would naturally be common over the pahoehoe part of it where the stream begins to pass to the aa condition.

The *bomb-like masses*, concentric in structure, observed over aa streams (xxxiv, 364, and in the figure on page 100), varying from an inch to a mean diameter of 10 feet, appear to be produced through the rolling movement in the forward portion of the advancing aa stream, due to friction at bottom (p. 101). They are often a heap of fragments of scoria inside with a

crust of solid lava outside, or consist of a series of concentric layers.

Dr. H. J. Johnston Lavis, who has studied with much care the Vesuvian lavas and eruptions, shows in his paper on "Fragmentary Ejectamenta of Volcanoes,"* that the "volcanic bombs" of writers on European volcanoes are not bombs any more than those of Mt. Loa; that they were not projected into the air; that they occur scattered over lava streams in great numbers when the adjoining country is free from them, and occur within lava streams; that they vary in size from a walnut to some cubic yards, and yet have often a thin shell and friable nucleus; that they "occur most commonly by far on the surface of lava-streams whose surface is rough and scoriaceous, instead of corded." He regards them as formed of lapilli that fell upon the flowing lava, and "in consequence of its forward motion became incorporated with it, and may undergo partial fusion, but usually congeal around themselves a coating of the parts in which they are involved." The description shows that the bomb-like masses of Hawaii are essentially identical in origin with the "volcanic bombs" of Europe. *Ejected blocks* are, as Dr. Johnston-Lavis remarks, wholly different in origin.

4. *Lateral Cones.*

Lateral cones are a frequent result of eruptions on Hawaii and the other islands of the group, although the lavas are basaltic. They occur, as in other volcanic regions, along the courses of fissures; along a flow of lava where fissures for supplying lavas are underneath it; and also in and about the summit crater. Whether they consist of lava-streams, or of cinders (lapilli) depends on the supply of heat as well as of lava in the vent (xxxv, 28); and whether the cinders make cinder-cones or tufa cones, on the supply of moisture connected with the eruption, much descending moisture giving a mud-like flow to the ejected cinders, whence the low angle and saucer-like crater of the tufa-cone.

They appear to be most common over the lower portion of a lava-stream, toward or along the sea-border; and it may be that this is due to the presence of more subterranean waters about the lower or foot slopes. A lateral cone of either of the three kinds is good evidence of a fissure beneath as a source of the ejected and pericentrically deposited material; and this evidence from them gives their occurrence especial interest. Where a stream of lava enters the sea and makes a cone of cinders or lava, there must be a fissure to supply the lavas and

* Proc. Geologist's Assoc., London, ix, No. 6.

projectile vapors, and thus to produce the upward throw of cinders and the pericentric deposition and stratification which are the marked features of a lateral cone. No such shape or structure can come from the simple discharge of a lava-stream into the sea, however rapid its progress; for this merely puts the fragments that are made at the disposal of the waves or currents along the coast, and the heaps piled up will be such as the action of waves and currents may make elsewhere. It cannot imitate successfully the pericentric work of the volcano. For this work, a center of ejection, acting for successive days or weeks, is required.

2. EXPLOSIVE ERUPTIONS.

All the eruptions of Mt. Loa and Kilauea within the last 65 years, the period of actual history, have been, as has been stated of the ordinary kind, that is quiet ouflows. At each, the lavas of the crater have simply quit work and sunk out of sight; and the discharge thus begun, with the consequent down-plunge of the undermined floor, was nearly all there was of eruption so far as the crater was concerned.

But traditional history gives hints of an eruption in 1789—a century back within a year—of another kind; and the results are visible over the region around the crater of Kilauea, as already described (xxxiv, 359). Similar evidences exist of an explosive eruption in the summit crater, as may be inferred from the descriptions of Mr. Brigham (p. 23) and J. M. Alexander (p. 31), as well as the earlier of Captain Wilkes,* and also in that of Hualalai.

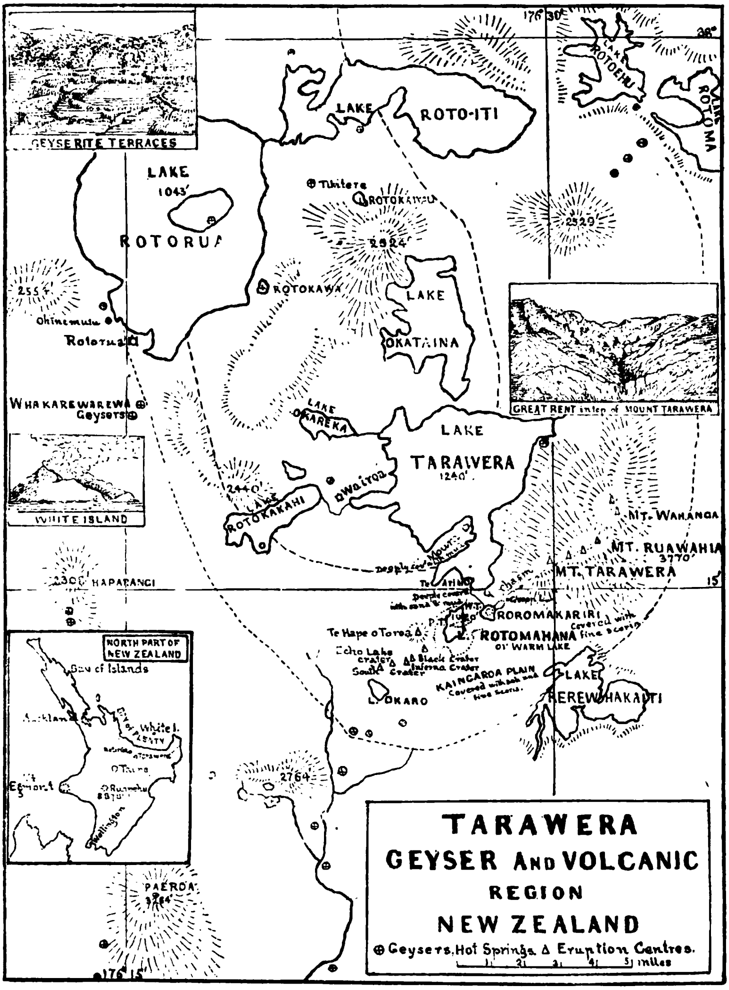
In the cases here referred to, the ejected material includes solid masses of the basalt, much of it very compact, and some of the blocks 50 to 100 cubic feet in size. For such work, instead of a cessation of the ordinary projectile action of the crater and a quiet discharge of the lavas when the eruption began, there must have been an enormous increase of projectile power, with great rendings of the rocks within reach of the up-thrust action. The eruption was not a quiet outflow, but a catastrophic up-throw. Whether accompanied or not by an outflow of lava is unknown.

Examples of explosive eruptions from Tarawera in New Zealand, and Krakatoa an island just west of Java, will make clear what is meant distinctively by an explosive eruption.

In 1886, in the Tarawera geyser region after some earth-shocks, a projectile eruption of terrific violence and incessant

* Wilkes speaks of large bowlders of a grayish basalt at the summit which had apparently been ejected from the crater (p. 159).
The precise date of the Kilauea eruption is in some doubt.

detonations began. Scoria and volcanic ashes or sand were thrown to a great height, that drifted with the wind and covered the country thickly and far away with ashes, making darkness, over a breadth of several miles, all the way to the sea in the Bay of Plenty. The height as seen from Auckland, 130



miles distant, according to a measurement by Mr. Vickermann of the Survey Department of New Zealand, was 44,700 feet. The eruption was ended and the clouds of dust gone in six hours. The work was done so quickly and fiercely that no cinder cones were made by deposits about the place of chief discharge. No outflow of lavas took place.

The accompanying map and explanations will make the remarkable Tarawera events more intelligible.* It represents the Tarawera geyser region, its lakes, mountains, and other features. A small map to the left shows the northern New Zealand island, and the site of Tarawera in the N. 35° E. volcanic line of Ruapehu, Lake Taupo and White Island; and White Island is represented in its usual steaming condition in a sketch just above. The line of the eruption in 1886 extended in a N.E.-S.W. course from Lake Okaro through Mt. Tarawera and Mt. Wahanga. Lake Rotomahana at the time of the eruption was emptied and converted into a region of craters. This lake, previous to the eruption, had on either side, a geyser basin and one of the famous geyserite terraces of New Zealand; the "Pink terrace" on the west (PT on the map), and the larger and more beautiful "White terrace" (WT) on the northeast side with the geyser Te Tarata at its head. The outflowing waters of Te Tarata, descending the gently sloping surface to the lake, had covered an area eleven and a half acres in extent with its siliceous (or geyserite) depositions, forming a descending succession of whitish cream-colored and almost porcelain-like terraces. A view of a portion of the terrace is given in the left upper corner of the map. Both terraces were buried in volcanic mud and ashes, a mud volcano displacing the geyser basin. A sketch to the left represents (from a photograph by Mr. C. Spencer), the region of the "great chasm," 200 yards and more wide, made in the Tarawera range at the outbreak; and the map gives its position, and also the positions of the several centers of eruption along the region. The outer dotted line on the map encloses the part of the Tarawera region that was covered with volcanic ashes, mud and scoria, and the inner, the portion of the larger area that was buried beneath mud; and the latter includes the buried villages of Te Ariki, Moura and Wairoa, where there was destruction of life, as well as a general obliteration of houses. Subsidences continued to take place along the great opened fissures for weeks after the eruption had ceased.

At Krakatoa, in 1883, the projectile discharge was equally sudden, and far more terrible and destructive. The height to which the dust was carried was made by Professor Verbeck 50,000 feet. It began in the early morning of one day, made day into night (by its ejections of ashes) for 36 hours, and left the sky clear by the close of the next day. Nothing is said of an outflow of lavas.

The earthquakes at Tarawera were not violent; they were felt to a distance of 50 or 60 miles only; and a dozen miles from Tarawera Mountain, at Rotorua, on the geyser plains, no shock was able to upset a chimney or jar down crockery from

* The facts here given are from an account of the eruption by T. W. Leys, 56 pp. 8vo, with maps and other illustrations, Auckland, New Zealand, and the Report of S. Percy Smith, Assistant Surveyor General, 84 pp. 8vo, Wellington. The height of the ejections above given is cited from the latter work, page 29.

a shelf. They were manifestly local, and had their center near the surface—an effect, not a cause; and they thus prove that the immediate cause of the eruption was local. The facts as to the Krakatoa earthquakes are similar. The deafening roar in each was made chiefly by the violent projectile action, the incessant detonations and the thunderings of a storm.

Such eruptions are of a wholly different cast from the ordinary outbreaks and discharges of Hawaii. The projectile agent must gain access to the conduit lavas to produce such extraordinary violence.

The eruption of Tarawera Mountain was probably brought about by the opening of a fissure that let subterranean waters *into* the reservoir of lavas; for Lake Rotomahana, situated on the line of fracture and only three or four miles distant, lost its waters, and probably in the process of supplying water for the projectile work. The volcanic mountain had been long extinct; but the widely distributed geysers and boiling springs were testimony to the existence of liquid lavas just below the reach of descending atmospheric waters. The geyser lakes of Rotorua and other localities became hotter during the night of the eruption and continued so afterward. Under such conditions an old volcanic mountain, perhaps hollow from former discharges, might be burst open again. Had the ingressing waters passed into the lava-reservoir *at a great depth* below the surface, the generated vapors would necessarily have added outflows of lava to the projectile discharge.

The volcano of Krakatoa, was probably started into action by a similar incursion, but of marine waters.

In both cases there were enormous chasms and crater-like depressions made, with a loss of the old foundations, and of the rocks that occupied the depressions. But the facts, while they include the projection of large stones over the vicinity, show positively that the stones were few compared with what would be needed to fill the great cavities left in the region. The explosive eruption blew to great heights fragments of the liquid lavas in the shape of scoria and sand or ashes, but did not blow off the solid rocks of the mountain. The disappearance of these and the making of the cavities are explained by the engulfment or down-plunge of material *to fill the space left empty* by the projectile discharges.

An *explosive eruption* is then simply one in which the projectile action, instead of ceasing at the time of eruption, becomes enormously increased; in which the erupting agent, instead of being roused to action outside of the lava-conduit, gains access to its interior, and hence the terrific boiler-like explosion.

For further explanation I repeat that the *ordinary activity*

of a volcano consists in the more or less high projection of cinders or of liquid lavas, with usually a great increase in the height as the crisis of an eruption approaches. In such action, there is nothing of the explosive work above described; neither is it entitled to be called a state of eruption; it is only a state of activity. Stromboli is perpetually at work in the *ordinary* way, with great variations in activity, "exhibiting the nature of volcanic action in its true light;" but it is not in "perpetual eruption;" no true eruption of this volcano, non-explosive or explosive, has been recorded in recent times. A volcano often gasps out its life in cinder ejections; for this is the meaning of the summit cinder cones of Kea, Hualalai, and Haleakala. It is still true, however, that cases occur in which it is difficult to decide whether the condition is that of ordinary activity or of true eruption.

The results of the projectile eruption of Kilauea, mentioned in the earlier part of this paper (xxxiv, 359–361), need not be here repeated. We learn from the deposits made by it that the eruption began in bombarding style—the projection of great stones to a distance of one to two miles, ranging to a height a thousand or more feet above the place of discharge; and ended in a widely extended shower of scoria and ashes. The finer material, besides covering all the borders of Kilauea, spread for miles to the southeastward, southward and southwestward. It constitutes, as I learn from Mr. Baker, the sand of the Kau "desert" described as ten by fifteen miles in area, and makes the bed, for six or eight miles, of an excellent carriage road between the crater and the ranch nearly half-way to Keauhou.

The evidence that the great stones were from the throat of the lava-conduit and not from the walls of the crater consists in their comprising, both east and west of Kilauea, kinds not found in the walls; and also many blocks of lava whose vesicles are lined with minute crystals of pyroxene and a plagioclase feldspar (as determined by Professor E. S. Dana), which are proof of subjection to long-continued heat. The walls of Kilauea are out of the reach of such upthrust or projectile action.

The explosive eruption of the summit-crater is of unknown date. As some of the ejected stones are fifty pounds to a ton in weight, it was probably similar in character to that of Kilauea; but the facts need further study.

Explosive eruptions at Kilauea and Mt. Loa are exceptional occurrences. In my examinations of the well-stratified walls of Kilauea I found evidence only of layers of lava—that is of old lava streams. But thin beds of stones and scoria might occur at intervals without making much impression on the

mountain or leaving very apparent traces in the walls. The summit crater, as described by visitors, has, like Kilauea, walls made of the edges of lava streams, without intercalations of prominent beds of scoria or other fragmental material.

II. Metamorphism an Effect of Volcanic Conditions.

The projected rocks of the region about Kilauea are a prominent source of evidence as to metamorphism by means of volcanic heat—as remarked on page 289 of volume xxxv; and other facts of like import are derived from the lava-stream tunnels and caverns. The rocks referred to, and those also of the lavas generally, as well as the cave-products, will be described by Mr. Dana in a following part of this volume. I briefly mention here a few of the facts that have a special bearing on metamorphism.

1. The minute crystals in the cavities of the ejected masses, instead of being zeolites, such as exposure to the weather might have produced, have been proved by Mr. Dana, as has been stated to be identical with the anhydrous constituents of the lava. Minute transparent acicular crystals have given him the angles of pyroxene; white rhombic tables, the characters of a triclinic feldspar, so that they are probably labradorite; and besides, there are brilliant iron black octahedrons of magnetite and tables of hematite or titanic iron. These are all the constituents of the basalt except the less constant one, chrysolite.

2. The caves and tunnels of Kilauea and of the Mt. Loa lava-stream of 1880–81, afford stony stalactites, remarkable for their slender pipe-stem-like size and form, scarcely tapering at all except at the extremity, where there is usually a short irregular twist. The diameter is hardly a fourth of an inch. In 1840 I found only short specimens in the caves of Kilauea; but in 1887 in the tunnel of the lava of 1880–81, near Hilo, many were 20 to 30 inches long; and in some undisturbed parts of the tunnel there were thickets of these, long gray-black stalactites, one every six or eight inches. Over the floor beneath each, there is a column of stalagmite of similar nature, which is a heap of bent coalescing drops or anastomosing stems from a few inches to fifteen or more in height. Most of the stalactites were solid, with occasional cavities, but many were tubular. Mr. Brigham observed them in the Kilauea caves in 1864–5, and has good figures on page 463 of his Memoir.

These stony stalactites appeared, under a pocket lens, to be identical with the rock of the lava-stream, even to the laths of labradorite, and the cavities showed minute transparent acicu-

lar and tabular crystals, besides black octahedrons of magnetite. The microscopic investigation of Mr. Dana proves that they actually are like the lavas in constitution, and that the crystals are of pyroxene and feldspar as in the ejected blocks.

The origin of the stalactites of the tunnels and their crystallizations is due, as I state in my Expedition Report (p. 201), to "the action of steam on the roof of the cavern." In the case of the tunnels the flowing lavas left behind a chamber filled with superheated steam, and under its action the solution and recrystallization went forward.

This reproduction of the basalt and the making of the crystals in geodes, or as linings of fissures, are examples of metamorphic work. It is metamorphism of the *crystallinic* kind*, the same which takes place when a feldspathic sandstone is converted into granite or granulyte, or when calcyte is changed into marble; and it is therefore one of the common kinds of metamorphism.

4. The ejected blocks about Kilauea instruct us on another point of much geological importance. They show that the throat of a volcano is necessarily a region of metamorphic action. It is a region of continued heat; and heat always works change when moisture is present. Under such conditions, therefore, an Archæan limestone or other Archæan rock containing chondrodite, spinel, vesuvianite, scapolite, anorthite, nephelite, biotite, might lead to the production of recrystallized chondrodite (humite), spinel, vesuvianite, scapolite (meionite), anorthite, nephelite, biotite (or meroxene) as metamorphic results; and in just the situation where an explosive eruption might detach masses and bring them up to the light. It is noteworthy that the above minerals of the ejected blocks about Somma, which have long been regarded as throat minerals of Vesuvius, crystallized by the volcanic heat as held by Scacchi, are kinds that are characteristic of Archæan rocks and especially of an Archæan limestone, rocks which may underlie the later limestones and other strata. There is little assumption therefore in saying that some of these crystallizations illustrate specifically crystallinic metamorphism, though others may be of the metachemic kind, that is, products of chemical change.

From the side of a fissure near the bottom of the emptied basin of the lava-lake called the "Old Beggar," was taken, at my visit in August, 1887, a specimen as large as the hand, covered with minute white tabular crystals, with some transparent crystals of acicular form. The mineral turned out to be gypsum, common as an incrustation in Kilauea caves.

* "On terms applied to metamorphism," this Journal, III, xxxii, 70, 1886.

III. The form of Mt. Loa a consequence of its Eruptions.

Mt. Loa differs from almost all other volcanic mountains in having a double curvature in its profile, owing to the flattening and widening of its summit, and the spreading of its base. It is the flattened summit which gives so vast bulk to a mountain of its altitude.

This peculiarity I attributed in my Expedition Report, to the positions of the prevailing outflows, on the ground that discharges of lavas about the base tend to widen and flatten the base and give a single concavity to the profile on either side; that discharges at the summit, especially if in short streams, serve to elevate the summit and make still more pronounced the single concavity; but that discharges over the upper slopes and not over the summit, tend to widen the upper part and flatten the summit so as to produce a convexity in the profile above.

The outflows of the century have had the distribution required to produce the actual form. Part are basal; another large part start just below the summit, and none of much size from the vicinity of the summit crater. The double curvature so produced, however, is mostly confined to the eastward and south-southwestward slopes, the chief directions of expansion by basal outflows; moreover, the widening in the former direction owes much, beyond doubt, to the eruptions of Kilauea. Further: *owing to the absence nearly of cinder-ejections*, the summit fails of the most common means of growth in height with tapering top; and this is a prominent source of the difference between it and most other volcanic mountains.

Another cause tending to modify the shape of the mountain is that producing fractures and subsidences. Its effects are seen about the great craters, and still more pronounced about the borders of the island. The former action aids in making summits broad and flat, while the latter works directly against the widening of the coast region. It makes the greatest fractures, nearly parallel with the coast and drops the coastward block; it thus tends to shorten the radius of that part of the mountain and put precipices into its profiles, increasing thereby the mean slope. Two such walls in southern Hawaii, cross the road between Keauhou and Kilauea, one about a mile and a half from the coast and the other three miles; they are marked features before the traveler in his ride from the coast to the volcano. These faultings seem to be a reason for the concavity in the southern coast-line from Keauhou westward, and for the short distance in that direction between the summit and the coast. Other great fault-planes exist; but the government map of the island should be completed before the facts can be satisfactorily discussed.

Sagging from pressure and consequent crushing has been made a cause of a single concavity between the top and the base of a volcanic mountain, and mathematical calculation has found a conformity between physical law and the shapes of such mountains in Japan and America. But there can be no crushing from gravitational pressure in a mountain made almost solely of lava; and it is hardly a possible result in any existing cone if made up even one-half of lava-streams, braced as they are by dikes.

The following are the mean slopes of Mt. Loa from the summit along different radii. The distances made the basis of the calculations are taken from the Government map:

S.S.W. to the southern cape	1 : 13·1=4° 22′
S.E. by S. to the indented Kapapala shore	1 : 9=6° 20′
S.E. to foot of slope W. of Kilauea	1 : 9·12=6° 15′
E.N.E. to shore at Hilo	1 : 14·86=3° 51′
W. by S. to western shore	1 : 8·11=6° 43′
N. by E. to plain between Loa and Kea	1 : 9 to 1 : 10=5° 50′ to 6°

In a circle of five miles around the summit crater the mean slope is about 3° : the mean depression to the eastward at the perimeter of the circle is about 1400 feet.

From Kilauea to the eastern cape, 28 miles, the slope is 1 : 36⅛ =1° 35′.

The fact that Mt Loa as well as Kilauea were made over a great fissure has given an oblong and approximately elliptical or ovoidal form to all the upper contour lines of Mt. Loa. Further, the bend in the longer axis of the summit crater, making the concavity to the eastward, is also expressed, according to the large government map, in the form of the upper part of the dome.

At what period in its history, Mt. Loa left off superfluent discharges and took to having only the *effluent*, or those through fissures, it is impossible to say. But as the walls both of Kilauea and the summit crater are made up of the edges of lava-streams to the very top, it would appear that summit overflows from the crater may have continued in each to a comparatively recent time. It is remarkable that the north and west walls of Kilauea, which show well the stratification from top to bottom, have almost no intersecting dikes.

In the following paper, the relations of the Kilauea volcano to Mt. Loa will be considered, and the question as to the effects of volcanoes on the depths of the ocean.

[To be continued.]

[FROM THE AMERICAN JOURNAL OF SCIENCE, VOL. XXXVI, SEPT., 1888.]

ART. XVII.—*History of Changes in the Mt. Loa Craters;* by JAMES D. DANA.

[Continued from page 112.]

RELATIONS OF KILAUEA TO MT. LOA.

THE position of Kilauea "on the flanks of Mt. Loa," 9500 feet below the level of the summit, plainly suggests the idea of its later and dependent origin. If the two were begun at the same time, why, it is naturally asked, should not Kilauea have approximately the same size as Mt. Loa? With the same time to grow in, and a distance between the two nearly equal to that between Kea and Loa, and a crater as large and still active, would it have stopped at less than one-third the height and have raised its summit only 300 feet, at the best, above the Mt. Loa slopes?

Several of the islands, Oahu, Molokai, Maui, and perhaps also Kauai, consist of two volcanoes united at base, or are volcanically twins; and Hawaii is a double twin, one couplet consisting of Kohala and Kea, and the other of Hualalai and Loa, *provided* Kilauea is subordinate to Mt. Loa. In all the twins the *eastern* of the two combined volcanic mountains is the larger. But Kilauea, although the eastern on Hawaii and the easternmost of the whole group, is one of the smallest. The greater size of the eastern volcano in a couplet has come from its continuing longer in action; and this is proved not simply by the size, but also by the evidence of long extinction, and therefore long exposure to denuding agents, in the western mountain; that is by the depth and extent of the valleys of erosion, the time-marks, over it.* There is other evidence also

* As this evidence of the lapse of time is important, I here cite a few sentences from the chapter in my Exploring Expedition Geological Report, on the "Origin of the Valleys and Ridges of the Pacific Islands," pp. 379–392.

"Mount Loa, whose sides are still flooded with lavas at intervals, has but one or two streamlets over all its slopes, and the surface has none of the deep valleys common about other summits. Volcanic action has had a smoothing effect, and by its continuation to this time, the waters have had scarcely a chance to make a beginning in denudation. Mount Kea, which has been extinct for a long period, has a succession of valleys on its windward or rainy side which are several hundred feet deep at the coast and gradually diminish upward, extending in general about half or two-thirds of the way to the summit. But to westward it has dry declivities, which are comparatively even at base, with little running water. A direct connection is thus evinced between a windward exposure and the existence of valleys. And we observe also that the time since volcanic action ceased is approximately or relatively indicated; for it has been long enough for the valleys to have advanced only part way to the summit. Degradation from running water would of course commence on such slopes [windward slopes] at the foot of the mountain, where the waters are necessarily more abundant and more powerful in denuding action, in consequence of their gradual accumulation on their descent.

"Haleakala, or eastern Maui, offers the same facts as Mount Kea, indicating the same relation between the features of the surface and the climate of the dif-

in the fact that the slopes of the western of the mountains in each twin island are partly buried by the more recent lavas of the eastern—Kohala by those of Kea, western Oahu by those of eastern.* The order in time of extinction thus derived, which my Report presents, is as follows:

1. Kauai.
2. Southwest Oahu.
3. Western Maui.
4. Kohala, on Northwest Hawaii.
5. Northeast Oahu.
6. East Maui.
7. Mt. Kea, Hawaii.
8. Mt. Hualalai, Hawaii.
9. Mt. Loa and Kilauea.

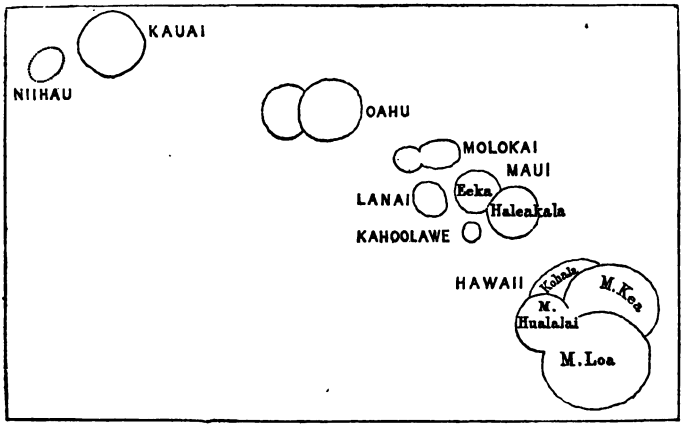
ferent sides of the island. On eastern Oahu the valleys are much more extensive; yet still the slopes of the original mountain-cone may be in part distinguished. And thus we are gradually led to Kauai, where the valleys are very profound and the former slopes can hardly be made out. The facts are so progressive in character that we must attribute all equally to the running water of the land. The valleys of Mount Kea, extending some thousands of feet up its sides, sustain us in saying that time only is required for explaining the existence of any similar valleys in the Pacific. As in Tahiti, these valleys in general radiate from the centre, that is, take the direction of the former slopes; they often commence at the central summits and terminate at the sea-level instead of continuing beneath it." (pp. 384, 385.)

"With literal truth, therefore, we may speak of the valleys of the Pacific islands as the furrowings of time and read in them marks of age. We also learn how completely the features of an island may be obliterated by this simple process, and even a cluster of peaks like Orohena, Pitohiti and Aorai of Tahiti, be derived from a simple volcanic dome or cone. Mt. Loa alone contains within itself the material from which an island like Tahiti might be modelled that should have nearly twice its height and four times the geographical extent." (p. 391.)

"We need add little in this place on the capabilities of running water after the statement, based on mathematics, that the transporting power varies as the sixth power of the velocity. If we remember that these mountain streams at times increase their violence a million-fold when the rains swell the waters to a flood, all incredulity on this point must be removed." "There is everything favorable for degradation which can exist in a land of perpetual summer; and there is a full balance against the frosts of colder regions in the exuberance of vegetable life, since it occasions rapid decomposition of the surface, covering even the face of a precipice with a thick layer of altered rock, and with spots of soil wherever there is a chink or shelf for its lodgement. The traveller ascending a valley on one of these islands on a summer day, when the streams are reduced to a mere rill which half the time burrows out of sight, seeing the rich foliage around, vines and flowers in profusion covering the declivities and festooning the trees, and observing scarcely a bare rock or stone excepting a few, it may be, along the bottom of the gorge, might naturally inquire with some degree of wonder, Where are the mighty agents which have channeled the lofty mountains to their base? But though silent, the agents are still on every hand at work: decomposition is in slow but constant progress; and the percolating waters are acting internally if not at the surface. Moreover, at another season, he would find the scene changed to one of noisy waters careering along over rocks and plunging down heights with frightful velocity, and then the power of the stream would not be disputed." (p 389.)

* The wonderful valleys of Kohala are given on the map of Hawaii, making Plate 1 of this volume. They are some of the deepest, most abrupt, and most beautiful in the islands, and are well described in Miss Bird's Six Months in the Sandwich Islands. Subsidence may have been concerned in the origin of part of them.

Here again the system seems to require that Kilauea should be made an appendage to Mt. Loa. I reproduce here from my Report the cut drawn to show these relations of the constituent volcanoes. In this diagram Kea and Hualalai are made to spread too far over Kohala, the central region of which should have been left uncovered; but the general idea conveyed is I believe correct.



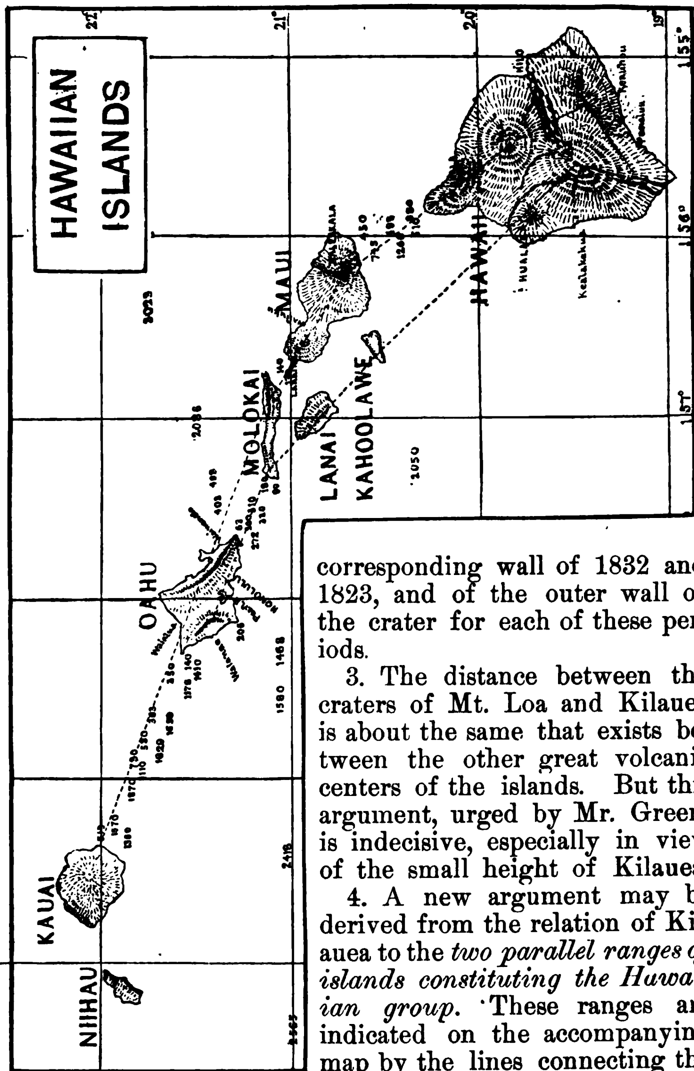
On these grounds, I concluded, in 1840, that Kilauea originated over a great fissure made at some Mt. Loa eruption.

This conclusion is not accepted in the report of Mr. W. T. Brigham, Captain C. E. Dutton, or Mr. W. L. Green.

1. The apparent independence of action in Kilauea is one of the opposing arguments; and it is a strong one. There is commonly no sympathy in their movements, although both have craters of unusual magnitude which are in frequent eruption and essentially in continuous activity; and although the open vent of Kilauea with its boiling lavas is but 3600 feet above the sea-level (in 1840 but 3000 feet) against 12,900 for the Mt. Loa crater. They have had some nearly simultaneous eruptions; but the larger part of the greater eruptions of Mt. Loa have taken place while the lava-lakes of Kilauea were in a state of undisturbed ebullition. There was remarkable harmony of action in the earthquake eruptions of the two in 1868; but it has been shown that the earthquakes which set off Kilauea were of Mt. Loa origin, made through Mt. Loa fires, and having their centre over thirty miles distant from Kilauea beneath the Mt. Loa slopes; and this harmonious action therefore does not indicate much sympathy between the two fiery neighbors after all.

2. In August, 1887, my examination of the walls of Kilauea

on the side toward the summit of Mt. Loa resulted in discovering no great dikes or other signs of former dependence on Mt. Loa. This evidence is not of great value, because the wall now exposed to view may be far inside of the wall of the greater original crater, just as the wall of the "lower pit" of 1840, which was in general without dikes, was inside of the



corresponding wall of 1832 and 1823, and of the outer wall of the crater for each of these periods.

3. The distance between the craters of Mt. Loa and Kilauea is about the same that exists between the other great volcanic centers of the islands. But this argument, urged by Mr. Green, is indecisive, especially in view of the small height of Kilauea.

4. A new argument may be derived from the relation of Kilauea to the *two parallel ranges of islands constituting the Hawaiian group.* These ranges are indicated on the accompanying map by the lines connecting the islands. The northern or "KEA

range," as I call it in my Expedition Report, includes northeastern Oahu, eastern Molokai, eastern and western Maui, and, on Hawaii, Kohala and Kea; the *southern* or "LOA range" comprises southwestern Oahu, western Molokai, Lanai, Kahoolawe, Mt. Hualalai and Mt. Loa, "with Lua Pele [or Kilauea] on the flanks of Mt. Loa." The Loa and Kea ranges have a mean trend of about S. 60° E. To the eastward the line of each range inclines increasingly to the southward. The northern, in its course from Maui through Kohala to the summit of Kea, becomes S. 45° E. in trend; and the southern from Kahoolawe to Hualalai and the summit of Mt. Loa has nearly the same course.

Now the line of the northern or Kea range, if continued on with only a little more southing, strikes Kilauea; while that of the southern points southward far away from it. *Kilauea appears, therefore, to belong to the Kea or northern range* and not to the Loa or southern; and if so, it is not an appendage to the latter, or to Mt. Loa, one of its volcanoes.

There is seemingly a "clincher" to this argument. The great craters are generally situated over the intersection of two fissures, one of which is the course of the range of islands and the other transverse to it, as stated by Mr. J. M. Alexander.* Now the line of the Kea range strikes Kilauea very nearly at right angles to its longer diameter in accordance with this rule. Further, the line of the Loa range, or better a line from the summit of Hualalai, strikes Mt. Loa precisely in the same way. This coincidence, which the map well shows, seems therefore to prove that Kilauea belongs to the Kea range and not to the Loa. The substitution of a line from Hualalai for that from Kahoolawe is reasonable, because the fissures over which the Hawaiian volcanoes were formed were probably independent for each island, though conforming to the general system. The summits of Kea and Loa are corresponding points in the two ranges, and Kilauea is an advance of one stage beyond Kea in the Kea range; it is owing to this that the longer diameters of the Loa crater and Kilauea make an angle with one another of about 32°. It is interesting to note, also, that the longer diameter of the crater of Mt Loa, or especially its southern half, points to the top of Mt. Kea; and that a line from Loa to Kea is nearly parallel to one between Hualalai and Kohala; so that the parallelogram enclosed has angles nearly of 70° and 110°.†

* This volume, page 38.

† Mr. W. L. Green, in his "Vestiges of the Molten Globe," brings forward a theory for the origin of the general features of the globe, which supposes its deformation from contraction on cooling to have developed feature lines crossing at angles of 60°—a "tetrahedral symmetry"—and, subordinately to these other

Notwithstanding the independence of Kilauea, there may still at times be evidence of some sympathy; for the two great active lava-columns are only twenty miles apart.

The evidence does not make it certain, however, that Kilauea originated as early in the history of Hawaii as either Kea or Loa; for the original fracture extending in that direction from Kea may at first have been sufficient only to let out a flood of lavas, and subsequently have been further opened and crossed by a greater fissure, so as to produce over it the permanent Kilauea vent.

5. Whatever the fact as to the relations of Kilauea and Mt. Loa, I believe they still sustain my old conclusion that volcanoes are not safety-valves;‡ for "if while Kilauea is open on the flanks of Mount Loa, lavas still rise and are poured out at an elevation of 10,000 feet above it, Kilauea is no safety-valve even for the area covered by the single mountain. Volcanoes are indexes of danger; they point out the portions of the globe which are most subject to earthquakes." The safer place is somewhere else. And among volcanic mountains, one that is really dead is a preferable neighbor to the volcano that has been smouldering from time immemorial. For the emission of heat by hot springs, geysers or fumaroles within a dozen miles is pretty good evidence, as at Tarawera, New Zealand, that liquid rock is at no very great depth below; too deep to receive from descending waters the moisture that may contribute energy to the fires and produce volcanic activity, but not too deep to be opened on an extreme emergency, so as to give entrance to a flood of waters for the most terrific of eruptions.

CONTRAST BETWEEN VOLCANOES OF THE MT. LOA AND VESUVIUS TYPES.

The marked contrast between volcanoes of the Mt. Loa and Vesuvius types based on the liquidity of the lava, making Mt. Loa discharges to be almost solely outflows, and those of Vesuvius, both upthrows of cinders and outflows of lava, has been sufficiently explained (xxxv, 28). With this exception, the contrast as to their eruptions, as well as to their ordinary action, is far less than is generally supposed.

lines at right angles to the sides of the triangle. His map of the Hawaiian Islands, which is covered with triangles, represents one of these lines as meridional, and one accordant, consequently, with the mean trend of the group, or nearly so. On page 147 of his work, it is stated that confirmation of his hypothesis is seen in the fact "that the direction of the longer axis of the elliptical craters of Mokuaweoweo and Kilauea is N. 30° E." But the facts appear to be that the longer axes of the two craters diverge 32° in direction, and that of Kilauea has nearly the course N. 52° E. Moreover, the trend of the island volcanoes of the group varies greatly in going from one end of the range to the other, and in this the Hawaiian is like other ranges over the ocean.

‡ Expl. Exped. Report, p. 221.

There is no reason to regard the forces as different in kind or mode of action. If the outside waters gain slow access, at depths below, to the lavas for the ordinary action of a volcano in Hawaii, they can at Vesuvius; and the force from the escaping vapors that, in this ordinary action, will make jets of lava of 30 feet to 600 feet, will make jets of cinders of far greater height. Moreover, as the erupting force at Mt. Loa in non-explosive eruptions, is not due to vapors inside the lava-column, since it does its chief fracturing part way down and sometimes far down the mountain instead of about the summit, and causes a quiet condition in the crater instead of violent action, so it is essentially at Vesuvius. In *explosive* eruptions at Vesuvius, on the contrary, the explosive force is due to vapor-generation inside of the lava-cauldron, the projectile action being vastly increased, as at Tarawera in 1886 and Krakatoa in 1883 (page 104).

As the observations at Vesuvius of Scacchi and others have shown (and my own two visits to Vesuvius, one just before an eruption, enable me to appreciate) high-lava mark in the volcano, or that of readiness for a discharge, is attained in the same way essentially as in Kilauea. After a down-plunge following an eruption (as a result of the undermining), leaving the crater hundreds of feet in depth and the upper extremity of the lava-column at a still lower level, work again soon commences, provided the lava-column was not so profoundly cooled off by the aggressive waters and vapor-generating as to be left too deeply buried. For a while the fractures in the bottom of the crater emit only vapors. Later, projectile action begins at one or more points, making conical cinder-deposits by the pericentric action, with now and then an addition to the inside accumulations from small outflows of lava about the bases of the cones or from their vents. The throws of cinders and flows of lava are kept up at irregular intervals, and the level of the floor rises. After the height within has become much increased, small fissures occasionally open through the outside slopes and let out some lava; but the ejections are mostly retained inside except in the later period of progress when some of the high-thrown cinders may fall over the outside of the mountain or drift away with the wind. Years pass; and finally the crater's bottom, bearing a large cinder cone, or more than one, reaches that high level in which it becomes actually the summit-plain of Vesuvius, and the fires are visible in the cracks of the plain because the liquid lavas are not far below it.* High-lava mark is thus attained and an eruption may be at hand. Severe earthquakes are not needed in the work any more than at Kilauea.

* I may refer here to a cut representing Vesuvius in this condition in my Text-book of Geology, made from my sketch in 1834, and to a paper in this Journal for 1835.

How far the ascensive force in the lava-column contributes to the change of level in the floor of Vesuvius nobody knows. The question has hitherto hardly been considered. It probably does its part, for, the liquid lava rises with the rising floor, following it closely.

With the column of liquid lava thus lengthened, making the mountain ready for a discharge, the danger of catastrophe is great for the same reasons as at Kilauea. But the danger is greater than there. It is greater because the forces from vapor-generation and hydrostatic pressure have a weaker mountain to deal with—one that has steeper sides and therefore thinner walls to the lava-cauldron, and walls that are partly cinder-made. It is greater because also of the nearness of the lava-column to the sea, the distance being only four miles, while in the case of Kilauea it is over nine miles and in Mt. Loa over twenty; so that at Vesuvius water from two sources, the sea and the land, is close by.

Causes that produce earthquakes may make a rent in the Vesuvian lava-conduit that will let in water for an *explosive* eruption; but usually it opens the way, as at Mt. Loa, for a comparatively quiet escape of lava, however disquieting the event may be to deluged villages.

The loss by upthrows and outflows tends to produce a sinking or down-plunge of the floor of the crater, and some fall of its walls to the new bottom, as in Kilauea. At the Kilauea eruption of 1886, the outflow drew off the lavas of a lava-lake half a mile in diameter; the crust of lava that covered the borders of the lake, along with portions of the walls, consequently sunk down, and the cavity or crater left by the discharge was half a mile across and between 500 and 600 feet in depth. This is little different from the ordinary event in Vesuvius, except that the loss by the discharge at Kilauea is almost solely by outflow, and no high, weak-sided cone surrounds the vent to suffer from the disaster. It is true that the Kilauea lava-lake in the eruption just referred to occupied only a small part of the great crater. But its diameter was as large as the lava cauldron of Vesuvius has been before any of its modern eruptions; and the movements in the lake were the same that would take place were all Kilauea one great lake.

Explosive eruptions might prove more disastrous to a Vesuvian cone than to one of massive Mt. Loa style; but not because the explosion has the power of blowing off the mountain's summit—which failed to happen at Tarawera in 1885 although the vent was closed and is not a possibility when the vent is an open one—but chiefly because a steep-sided mountain is likely to lose more in height than a broad lava-cone from the same amount of undermining.

We may hence conclude that (1) Vesuvius and Mt. Loa are instructive examples of the effects of the same volcanic forces and methods under different conditions as to rock materials and heat; and (2) *systematic study inside of craters between volcanic eruptions* is what the science most needs.

In another paper, the results of volcanic action will be further illustrated from observations made, the past year and earlier, in the islands of Maui and Oahu.

[From the American Journal of Science, Vol. XXXVII, Feb., 1889.]

Art. X.—*Points in the Geological History of the islands* Maui *and* Oahu; by James D. Dana. With Plates III and IV.

The subjects prominently illustrated by the islands Maui and Oahu are: the conditions of extinct volcanoes in different stages of degradation; the origin of long lines of precipice cutting deeply through the mountains; the extent and condition of one of the largest of craters at the period of extinction; and the relation of cinder and tufa cones to the parent volcano. The other islands of the group present facts bearing on these subjects, but the writer's knowledge of them is too imperfect for review in this place.

I. Island of Maui.

The accompanying map, Plate 3, reduced from the recent large government map,* shows the general features of the island of Maui:

(1) The volcanic mountain of East Maui, Haleakala, 10,032 feet in height, having at summit, a crater 2500 feet in greatest depth and twenty-three miles in circuit.

* On this Plate, as on that of Hawaii in the last volume of this Journal, most of the lettering of the original map is omitted, with necessarily also minor details as to erosion and topography.

(2) The abrupt depression of Kipahulu, to the southeast of the summit, surveyed but not geologically studied, which looks as if it were the site of another great crater.

(3) The slopes of eastern Maui, little gullied by erosion, but most so on the side facing northeast—the windward side; and here the longest valleys scarcely reaching to the summit.

(4) The mountain of west Maui, a volcano in ruins, being profoundly cut up by valleys, and the original height reduced to 5788 feet as the maximum.

(5) The low intermont area of Maui, made of the united bases of the two volcanoes, but covered for the most part by the lava-flows of Haleakala, whose fires continued in action long after the western volcano was turned over, dead, to the dissecting elements; the width from north to south at the narrowest part, near the line reached by the lavas of Haleakala, about six miles, and the height at the survey station near its middle, 156 feet.

From my use of the maps of the Hawaiian government survey through the preceding memoir, and my frequent reference to them for facts about the volcanoes, craters and lava-flows, as well as the topography of the island, it has been apparent that they have been a very prominent basis for the conclusions presented. The government map of Maui has still greater geological importance; for Prof. Alexander, the surveyor-general, has made it, by his accurate work and his appreciation of the importance of details, a contribution to science of the highest value and interest. What I have to say of the extent, depth, form and discharge-ways of the great crater, of the heights and positions of cinder cones, and of the erosion of the mountains, should be put mainly to the credit of the map, which was Prof. Alexander's work not only in superintendence and geodetic measurement, but largely also in the details of the survey. The survey of the island, which is still in progress, reflects great credit on the Hawaiian people, and we trust it may be continued until in all parts complete. Every cone, or precipice, or fissure, terrace-level, or lava-stream located is a contribution to the history of the island and to physical and geological science.*

* I am, moreover, personally indebted to Prof. Alexander's kind providings, guidance and instructions for the success of my trip in 1887 (August 4 to 6) up Haleakala and into the crater, where a night was spent—an exceptionally brilliant night after a day of clear views from the slopes and the summit; and also for my excursion up Wailuku valley on western Maui.

I owed much also, while on the island, to the hospitality of Mr. Henry Baldwin of Haiku, Mr. Edward M. Walsh and Rev. Thomas Gulick of Paia, and Mr. Bailey and Rev. Mr. Bissell of Wailuku.

An excellent model of the island of Maui has been made by Prof. C. H. Hitchcock, who devoted much time to it during his recent visit to the Hawaiian Islands. The government map was the chief source of data for the details. The verti-

1. *East Maui.*

I. *The Mountain.*—The crater of Haleakala has been many times described, but first with a detailed map in illustration by Captain Wilkes. Captain Wilkes states that he is indebted for the map to his artist, Mr. Joseph Drayton;* and considering that it was from an artist's survey, not that of a surveying party with instruments, it is a remarkable piece of work. The expedition owes much to Mr. Drayton, not only for his excellent labors as draftsman in all departments at sea, but also, after his return, for his management of engravers, printers, etc., during the publication of the various Reports.

The mountain is usually ascended from Paia, a village on the north coast. The path (see map) passes Olinda and reaches the edge of the crater where the nearly vertical western wall bounding it is not less than 2500 feet in height. Thence it follows the summit southwestward to the southwest angle passing Pendulum Peak† on the borders of the crater just before reaching it. Here are three cinder cones, and the top of one is the culminating point of the mountain, 10,032 feet above tide. They stand at the head of a long line of cinder cones extending southwestward down the mountain to the sea; and near the sea at the foot of this line are three or four comparatively recent lava-streams, enough to illustrate the process of seashore extension by such sea-border outflows. From the southwest angle of the crater and the base of one of the three cinder cones, a cinder-made slope of rather easy grade descends into the crater, making a convenient place of descent; and thence the path continues eastward to the usual place of encampment, 4½ miles from the top.

2. *The two great discharge-ways of the crater.*—Besides its lofty walls and great area, the most remarkable features of the crater are the two openings, a northern and a southern, a mile to a mile and a half wide between precipitous walls of rock—the walls of the northern 2,000 feet and over, of the southern, 1,000 to 2,000 feet—through which poured the lava of probably the last of the great eruptions. The Kaupo lava-stream, the southern, has much the smoother surface, as if more recent; but the broader Koolau stream descended the *wind-*

cal height is increased four times, and the craters and valleys are thus strongly brought out. All such exaggerated relief maps, whether of a mountain or sea-basin, need a note of warning attached to prevent wrong conclusions as to slopes and heights; for the ratio of 4 to 1 instead of 1 to 1 changes a slope of 14° to one of 45°, a low to an acute cone. The light shading used on the map of Hawaii in the last volume of this Journal and here on that of Maui, is intended to bring out the idea as nearly as may be of a mean slope of 7 to 10 degrees.

* Wilkes's Narrative, vol. iv, p. 255. In the Exploring Expedition I had no chance to visit Maui, and saw it only from ship-board when passing it.

† The Pendulum station of Mr. E. D. Preston, of the Coast Survey, in 1887 This Journal, last volume, page 305.

ward slope, and the consequent erosion may have made all the difference.

3. *The Cinder-cones and Lavas at the bottom of the crater.*—Another striking feature of the crater is the group of red and gray cinder-cones which stand over the bottom, sixteen in number; the highest 900 feet above its base and all over 400, and yet looking small in the view from the summit of the great area. The sight to the northward, when half way to the bottom, comprising the northern discharge-way in the distance, the highest of the cinder-cones in the foreground, and beyond these and two other cones the broad stream of lava of the crater-floor as level apparently as a river, stretching away between precipices of more than 2,000 feet and then terminating in an even line at the limit of vision as if there began the plunge to the sea, is wonderfully like the real river of lava on its downward way.

The cinder-cones of the bottom were evidently the last work of the fires. The ashy surface of the cones is without a trace of erosion and thus bears no distinct marks of age. The slopes are mostly 25° to 30° and less, and hence they may have had the pitch diminished somewhat by the winds and rains and earth-shocks, but there are no channelings by descending waters. The material is scoria in coarse fragments and sands, and though in part originally reddish and purplish, the red color has generally been deepened by oxidation from exposure.

Besides the scoria, there are on some of the cones, especially those toward the borders of the pit, numerous large blocks of gray, compact, scarcely vesiculated rock. Some of the masses about a cone near the place of descent measured over a hundred cubic feet. The masses must have been torn off from the throat of the volcano's conduit, this being the only conceivable source. They indicate therefore the action of vast projectile force at these isolated centers when the cones were in progress, and its continuation even to the close of the ejections; and they also are probable evidence of very rapid work in the cone-making. A few of the other cones were grayish in color as if from the abundance over their slopes of these projected grayish stones; but I was unable from want of time, to verify this supposition.

The cones stand, or appear to stand, on the rough, fresh-looking, scoriaceous lavas of the bottom, these lavas spreading away from beneath them. It was evident that the opened fissures or vents which gave exit to the cinders, first poured out the lavas; and then followed the cinder ejections as the fires declined and the liquid lavas of the vent became somewhat stiffened. The cinder material is proof of powerful projectile work; for the fragments of the exploding bubbles were thrown

upward, as the heights of the cones prove, many hundreds of feet—more than nine hundred to make the highest cone.

The fresh-looking lavas, occurring about the base of the more western of these cones, were found to continue eastward throughout the crater, with little change of features and with the same relation to the bases of the several cones, as if all were of one epoch of eruption—the epoch of the last outbreak of Haleakala; the lavas seemed to have come from the latest outflows of several subordinate vents, after the crater had made its great discharge through the two gateways down the mountains.

This scoriaceous lava of the crater contained in many places much augite and chrysolite in largish grains or crystals, being both augitophyric and chrysophyric.

4. *Lavas of the walls and summit.*—The lava of the walls was in part scoriaceous; but, where examined on the south and southwest sides, it was commonly a very compact, rather light gray variety of basalt, like that of the projected blocks about some of the cones. The layers of compact basalt had often one or more parallel planes of fine or coarse vesiculation, sometimes at intervals of one to three or four feet.

At one locality on the ascent of the mountain the solid gray rock had been found to be a convenient stone for stone implements of various kinds, and a large manufacture had apparently been carried on there; and yet near by, the lavas that were so solid had occasional planes of coarse vesiculation, each one to three or more inches thick. Pendulum Peak, near the summit, just north of the southwest corner of the crater (the place of descent) consists largely of this compact light-gray basalt, with rarely any vesiculation visible without the aid of a pocket lens.

This compact basalt or doleryte is a common rock also over the lower slopes toward Paia. It appears thus to be to a large extent the material of the older lavas; yet not only of the older. But at the summit on the west side, along the two miles passed over before reaching the place of descent, the compact variety of the basalt was rather the exception. There were large areas of the same scoriaceous lava that covers the bottom of the crater, and in some places it was equally augitophyric and chrysophyric, the augite in well-defined crystals. One of these areas was just north of Pendulum Peak; and a large region on the west border of the crater, looked as if successive streams of lava had recently flowed one over another, piling up layer on layer, so that by this means the surface for a breadth of a mile or more westward from the summit line had derived its unusual steepness of 15° to 16°. The lava-streams of the surface had the appearance of being overflows from the crater; as if the great pit had been full to the brim before the outbreak

and had poured out from time to time small streams like those of a full lava-lake in Kilauea. But they more probably came from fissures cut through to the summit at the time of the last or some one of the later eruptions.

The fact that lavas of the summit are so very chrysolitic, even at a height of nearly 10,000 feet, has an important bearing on the question as to the effect of high specific gravity in determining the distribution of materials in liquid lavas.

Crystals of augite and large grains of chrysolite are common in the loose material at the base of the cinder cones at the summit, near the place of descent, and colored glassy crystals of labradorite occur with them—facts first learned from Rev. T. L. Gulick after our return. These summit cones have the recent appearance and other features of those over the crater's bottom, and appear to be of the same series and time of origin; and the cinder-slope of that side of the crater was probably made in part from the ejections of these summit cones.

5. *The probable nature of the last eruption.*—The great discharge-ways of Haleakala, one to one and a half miles wide, with the walled valleys confining them, look as if the results of enormous rents of the mountain, made when the mountain emptied itself by the wide channels. But they may have been in existence before, and have been simply used for the last of the outflows. They are, nevertheless, evidence of rents at some time, and of a vast amount of removal of material some way—by subsidence, or otherwise. The height of the walls at the gaps, 2000 feet and over at the Koolau gap, and 1000 and over at the Kaupo, are a minimum measure of the amount of material removed. In my Exploring Expedition report I suggest that the mountain was fissured across along the lines of the two discharge-ways, and the eastern block shoved off a mile or two. But a subsidence of the masses that occupied them into caverns below, leaving the walls as fault planes, may be more probable. The abyss which received them in this case had been prepared during a long period of undermining through ejections. Still there is some reason to believe in the grander view of a subsidence of the whole eastern block, after the cross-fracturing. The island, as is seen on the map, is abruptly narrowed (instead of widened) at the spots where the Koolau and Kaupo streams reach the sea; and the part to the eastward is small, as if narrowed by such a subsidence. Moreover, the mean height of the eastern craterwall is lower than that of the opposite or western by 500 to 1000 feet. A subsidence of 1000 feet increasing in amount to the eastward would account for the narrowing and for the very short eastern radius of the eccentric volcano. The question merits consideration.

The evidence that the lavas were discharged in both directions at once at the last eruption consists in the nearly uniform appearance of the fresh lavas over the bottom of the crater from one end to the other, and their continuing into and apparently being the streams that descend the Kaupo and Koolau discharge-ways. Mr. J. M. Alexander has remarked that the crater is probably a double one, a combination of two great craters, as Mokuaweoweo at the summit of Mt. Loa is compound in structure. This is no doubt historically true; but at the latest of the eruptions there was probably one action over the whole, the distinction for the time obliterated.

The period of the last summit eruption is unknown. I learn from Mr. Bailey of Wailuku, Maui, that, according to an island tradition, a *lateral* eruption of the mountain occurred about 150 years since in the district of Honuaaula of the southern part of East Maui, at an elevation above the sea probably of about 400 feet.

6. *Activity of the Crater ending in Cinder-ejections.*—The origin of the *crater* of Haleakala needs, I believe, no explanation beyond that given in the remarks on the origin of craters generally: that a volcanic crater and the mountain containing it commence to form together about an opened vent which discharges both vapors and lavas; that the crater is a result of the projectile action and the discharge of material from below, and generally also of subsidence into the cavity which is made by the discharge; and that it does not become closed before the central vent ceases to discharge, and commonly is not then closed.*

Haleakala is an example of a basaltic volcano which reached its end, through declining fires, in cinder ejections; but it left its great crater open, and 2000 to 2500 feet deep, with the greater part of the bottom free from the cinders notwithstanding the amount discharged. The latest down-plunge or subsidence by which the vast pit and perhaps also its discharge-ways were made, may therefore have filled full the empty subterranean chambers which former outflows had produced, and left the mountain solid instead of hollow. Mt. Kea on Hawaii, 13,805 feet in height, also ended its work with cinder eruptions; but the ejected material of lavas and cinders obliterated so far the old crater that no visitor of the region has yet found traces of its former limits. Whether Mt. Kea is a hollow mountain or not remains to be ascertained.

Since the above was written, the results of the pendulum investigations of Mr. E. D. Preston at the summit of Haleakala have been made known in a paper published in the number of

* This J., xxxv, 33, Jan. 1888. The view is the same published in my Exploring Expedition Report, 40 years since.

this Journal for November last,* and have afforded unexpected evidence on these doubtful points. They have led him to the important conclusion that "the density of the mountain is at least equal to its surface density," and that, therefore, unlike some results obtained on the continents, "it is a solid mountain," so that the interior must have been left filled by the subsidence of rock that made the great crater at the summit. He states also that "the zenith telescope observations at the foot of the mountain indicate the same fact."

Mr. Preston states further that at Kohala, on the *north* coast of the island Hawaii, the plumb-line deflections were half a minute *southward*, which, he adds, is well explained by the position to the southward of all the great mountains of Hawaii. He records also that at Hilo, on the *east* coast, the deflection was a fourth of a minute *to the northward.* Mr. Preston remarks that "there is no explanation" of this result at Hilo "unless we assume that the south side of Hawäii, where the volcanoes are active, is much less dense than the north side where the fires have been slumbering for centuries." But to the north of Hilo is a long reach of ocean, the coast of Hawaii there trending northwest; the summit of Mt. Kea, 13,805 feet high, is 25 miles distant and bears N. 75° W.; and that of Mt. Loa, 13,675 feet high, is 35 miles distant and bears S. 63° W.; and the center of gravity of the combined mass (the lowest level over 5000 feet) bears probably a little south of due west. It appears, hence, that we have here evidence that Kea is like Loa, *not* solid; that it is a hollow mountain, as inferred above from the absence of a summit crater; but Mr. Preston is probably right in his inference that Mt. Loa is the more cavernous of the two. Additional plumb-line and pendulum observations are, however, much to be desired.

2. *West Maui.*

West Maui has lost the original slopes of its great cone and its crater through erosion. It has been supposed that remains of three great craters may be distinguished in the mountains: the largest at the head of Wailuku or Iao valley on the north border of which rises the highest peak, Puu Kukui, 5788 feet high; another in the less deep valley of Waihee, just north of this; and a third at the head of the Olowaiu valley, to the south.

I examined only the Wailuku valley, the largest of the three, —so named from the village on the coast near its entrance. The valley is a deep cut into the mountains, remarkably grand in its precipitous walls with thin crested summits. It widens

* Vol. xxxvi, 305.

somewhat toward its head, and in this upper part an extensive plateau occupies the center. The torrent of the valley is here divided between two tributaries, one running either side of the plateau. The height and rather bold sides of the plateau at the head of the valley, and its size and position, taken in connection with its location near the center of the mountain range, appear to make it pretty certain that the plateau represents the floor, or rather what is left of the central area, of the great crater. I looked for the edges of lava streams in the enclosing walls in order to make out their pitch and the thickness of the beds. But dense vegetation so covers everything that distant views are of no geological value, and one day's excursion was not sufficient for a climb of the heights.

As to the former crater condition of the other two valleys mentioned, I know nothing from personal observation. The idea of their having been craters is based on the size, depth, and boldness of the walls and the ampitheater-like head. But these features are common results of denudation in old volcanic islands, and therefore, in the question here considered I give them little weight.

3. *The Eccentric form of the Maui Volcanoes.*

The map of Maui illustrates a Hawaiian feature of volcanic mountains which may be common in other regions. The chief crater of the mountain is not at its center. In Haleakala the ratio of the radii east and west of the crater is 2 : 3; and in West Maui, 8 : 11. The shorter radius is to the south-southeast of the crater in one and to the southeast in the other.

In Hawaii it is not easy to mark off the true base of Mt. Loa. But we have the fact that in both the summit crater and Kilauea, the form is oblong, and each has its intenser activity in the more southern portion—the south-southwestern in one, and the southwestern in the other. The effect is not due to the to the winds, for the mountains consist almost solely of lava-streams.

4. *Drift-made ridge of consolidated coral sand.*

The positions of the high ridge of consolidated coral sand of Wailuku are indicated on the map. Whether proof of elevation or not is yet undecided. I was informed that the sands are at the present time drifted by the trade-winds to the farther inland limit of these ridges and over their surfaces—a fact which seems to show that present conditions are sufficient for their production.

II. Island of Oahu.

From the map of Oahu, Plate 4, it is apparent that the island (*a*) consists of two eroded mountain regions, an eastern and a western, separated by a plain sloping gently downward to the opposite coasts and upward toward the eastern mountains. A more remarkable feature (*b*) is the long and high precipice fronting northeastward, and thus facing the tradewinds. Besides these characteristics (*c*), there are lateral or subordinate volcanic cones on the sea-border, of which Diamond Head and its companions, Punchbowl, and the Koko Head craters on the eastern cape (Plate 4, figs. 1, 2, 3), are examples. The island is the only one of the group that has (*d*) a nearly continuous coral reef fringing the shores. It owes to this reef the harbor of Honolulu, the one good harbor of the group, and also the possibility of a much larger and better one at Pearl River, seven miles west of Honolulu; the cutting of a channel through the reef is all that is needed, as has long been recognized, to make these capacious inner waters available for shipping*. Another interesting feature (*e*) is the existence of an *elevated* coral reef on the borders of the island, having its inner limits approximately indicated on the map by a dotted line.

The facts on which the following account of the island is based and the views deduced from them are for the most part contained in my Expedition Geological Report. The visit in 1840 gave me nearly a month for study, which was industriously employed in excursions over and around the island. The accompanying map, on Plate 4, differs little, excepting in improvement in outline and topography, from the colored geological map of my Report, and the outline of the elevated coral reef and its coral rock and sand bluffs are copied from it. The view of the tufa cones on the same plate are simply new drawings from some of my old sketches. For fuller particulars and some views not reproduced—as those of Kaneohe Point and Aliapaakai, I refer to the Report. My recent visit (in 1887) gave me an opportunity for another excursion around a large part of the island (taken with President Merritt), and

* Honolulu, the capital of the Hawaiian Kingdom, was a collection of thatched huts in 1840, with exceptions only in a Custom House, an unfinished coral-rock church, and a few dwellings of civilized aspect. To-day it is city-like in its houses, its streets electrically lighted, its public squares, large Hospital grounds, spacious Government buildings—among them a palace good enough for any potentate—and its excellent hotel; and, through the addition of groves and avenues of introduced palms and tropical trees (some of which are always in flower or fruit) it is fast becoming a place of ideal beauty. Honolulu is the center of all the island activities, including inter-island navigation. It is not out of place to repeat here that steamers start every week or two for Hawaii and Kilauea—one route by Hilo to Keauhou, and thence up by horseback and wheels, the other by Punaluu on the south coast, where there is a good hotel and a carriage road all the way to the volcano. A carriage road from Hilo to Kilauea is in prospect.

for further explorations, refreshing old memories and adding new facts; and this return to the subject affords an occasion also for reconsidering former conclusions.

1. *Features, structure, and origin of Oahu.*

1. *General features; Contrast with the island of Maui.*—Like Maui, Oahu is in origin a volcano-doublet—that is, as regards rock-structure, it was the united work of two great volcanoes, a western and an eastern. But unlike Maui, its two volcanic cones or domes have suffered so great loss that the position of either crater is wholly a matter of conjecture.

A large part of the loss Oahu has suffered is due to denuding agencies. East Maui, as the map on Plate 3 illustrates, has lost in this way comparatively little of its original evenness of surface owing to the recency of its extinction. Its windward gorges are narrow, and only shallow gulches occur over the leeward surface. The ratio of its diameters at base, 1:1·3, is probably very near the original ratio. West Maui is profoundly gorged on all sides and most deeply so to windward, illustrating results of longer wear than East Maui has had. But something of the old slopes remain, and in the base we have still the ratio of its old diameters, 1:1·4, with the outline little indented. The double lesson is taught: (1) what denudation from descending waters does to a volcanic cone 5° to 10° in slope in the region of the trades; (2) what, on the contrary, the sea cannot do, no encroachments of note existing to attest to its power, notwithstanding the length of the era of denudation.

Oahu resembles Maui in having the western mountain-cone the most time-worn and the smaller in area, but here the likeness ends. Both of its mountains are deeply eroded. Further, East Oahu has only part of its old slopes left. They remain only on its southern, western and northern sides; the northeastern are cut off by the great precipice, twenty miles long, which is made for the most part of the edges of the lava-streams that slope southward and westward. The sharp-edged serrated ridge, making the summit of the precipice, is from 1000 to 3000 feet in height, and at its northeastern base, from Kualoa eastward, there is in general only a narrow strip of low land with low hills, the width but three or four miles except in the Kaneohe peninsula. The precipice continues beyond Kualoa northwestward, but not the low land at its base.

These features have occasioned peculiarities in the results of denudation on East Oahu. The leeward or south and southwestern sides have long and deep valleys, some of them heading in broad amphitheaters under the crested mountain ridge. The windward side, along the 20-mile precipice, on the contrary, has buttresses and shallow alcoves, with a but-

tress here and there lengthening out into a ridge; and only farther northwest, beyond Kualoa, are there the longer valleys or gorges and ridges and the mountain architecture characteristic of deeply worn windward slopes.

The only broad valley of the leeward or south and southwestward slope that is continued upward with gradual ascent to the very edge of the precipice is that of Nuuanu, behind the city of Honolulu. It is the valley to the left in fig. 2 on Plate 4. Six miles up it ends in the "*pali*," or precipice, and overlooks the northeastern sea-border plains and hills. The height of the "pali" is only 1207 feet above the sea; but on either side are the highest peaks of the range, Konahuanui 3105 feet in height, and Lanihuli, 2775 feet.

Great denudation on the *leeward* side of an island is an exception to the usual rule. It is a consequence, on Oahu, of the sharp-crested 20-mile precipice. The trade winds become chilled on striking the summit of the precipice and ready, therefore, to drop their moisture; but as they are moving on, they get beyond the summit before much of the moisture falls, and so the *leeward* slopes receive the water. In the upper part of the Nuuanu valley, within two miles of the *pali*, 132 inches of rain fall a year, and nearly 100 inches less than this at Honolulu, although brief sprinklings occur almost daily over the city. Konahuanui and Lanihuli, as seen from Honolulu are generally under clouds, but from Kaneohe they are usually uncovered.

A nearly similar condition exists in West Maui, owing to the thinness of the rocky walls at the head of its great valleys. Very broad valleys are consequently made on the leeward side, as in Oahu; but these valleys soon end below in a slender gulch, which may be, for the most of the year a "dry run;" the excessive dryness and heat of the lower plains evaporating powerfully and supplying no water.

2. *Orographic condition of East Oahu.*—From the facts mentioned, it appears to be plain that the chief structural difference between East Oahu and East Maui is that the latter is a whole volcanic mountain, and the former a piece of one. By some means the Oahu mountain-cone or dome has lost, as I concluded in 1840, a large piece from its mass—all that once existed northeast of the 20-mile precipice. The size of the lost piece it is not easy to determine. The lava streams of the leeward slopes, which dip away from the precipice mostly at an angle of 3° to 5° (as seen in the intersecting valleys), must have come from some point or points beyond it to the northeastward.

Following the leeward slopes around westward and northward we find all pointing upward toward the higher part of

the mountains, as if the source were somewhere in that direction; but just where, remains in doubt; and it may be even questioned whether there may not have been two or more great craters along the line.

No point or region has a more reasonable claim for consideration in this respect than the head of Nuuanu valley. In situation and width, and the features at its head, it is just what should be looked for in a great discharge-way. On my recent visit I sought for facts bearing on the question and found the dip of the beds to diminish from 3° to 1° toward the top, and at the "pali," the beds were very nearly or quite horizontal. This is favorable to the conclusion that the crater was either at its head or near by it, just beyond the precipice. The low land below, over the Kaneohe peninsula and between this peninsula and the "pali," is a region of tufa hills and other small cones, unlike any part elsewhere of the north or northeast coast. In addition, at the head of Nuuanu valley, very near the top of the "pali," there are the remains of a red cinder cone. Besides this, on descending the steep "pali" by the path, there is to the east of the path a long broad slope, 35° to 40° in angle, consisting of reddish layers of volcanic cinders, scoria, earth and stones—indicating cinder ejection from some point above.

It is therefore most probable that the center of volcanic activity for East Oahu was in the vicinity of the "pali," above the low region a little to the northeast of it. The cinder cones above mentioned may have been results of the last efforts of the declining fires, like those of Haleakala and Mt. Kea.

In 1840, I was led to locate the central crater on the Kaneohe peninsula, because the head of the "pali" was so near the southern foot of the mountain; I thought it must have been farther off. But the fact that the volcanic mountains of East and West Maui are eccentric in ground-plan, and that the same feature quite certainly characterized this Oahu cone, makes the position near the "pali" the most probable. In Haleakala the center of the crater is only six miles from the southern shore; and this distance in the Oahu crater, on the above supposition, would be about seven miles. The idea of an eccentric cone fourteen or fifteen miles in the transverse diameter through the crater is thus strongly favored. On further comparison with Haleakala, we find that the part of the longer diameter of the mountains which lies northwest of the center of the crater is about 19 miles in length on Maui, and on Oahu it would be nearly 25 miles. The small dip of 1° to 3° prevails widely about the mountains at Kualoa point and to the northward, as well as in the upper part of the Manoa valley, west of the Nuuanu; and from this it may be inferred

that mud-making warm waters were concerned in the deposition; and its being of brown, in place of red, color, is probable evidence that the temperature of the water was below 200° F.

Diamond Hill, fig. 1, makes the prominent cape east of the city; its bold southern brow has a height of 761 feet above the sea at its base. It is, like Punchbowl, a fine example of the typical tufa-cone in its broad and shallow, saucer-shaped crater, with the stratification parallel to the bottom of the saucer and to the original outer slope. These slopes have become deeply trenched, as the view shows, by descending waters; and since 1840, the southern brow has lost something of its boldness. Two other cones stand in a line to the north of it, the first, a place of lava outflow. The three vents appear to be situated on a single line of fracture.

The Koko Head tufa-cones are situated at the east extremity of the island. The view (fig. 3) was taken from the eastward at sea. The larger or more northern of the two cones is much denuded inside and out. The other low cone, situated on the Point, is worn to its center by the sea, and has thereby been made to exhibit to the passing vessel (as it goes from or toward Honolulu) the dip of its tufa beds inward and outward, and thereby the true structure of such a cone.

Artesian borings on Oahu afford some facts bearing on the history of Diamond Head and Punchbowl. The borings were made by Mr. J. A. McCandless of Honolulu, and records of a number of them have been received from him through Prof. W. D. Alexander.

The following section is from James Campbell's well, at the west foot of Diamond Head, not far from the sea-level.

	Thickness.	Depth.
Gravel and beach sand	50 feet	....
Tufa like that of Diamond Head	270	320 feet
HARD CORAL ROCK, like marble	**505**	**825**
Dark brown clay	75	900
Washed gravel	25	925
Deep red clay	95	1020
SOFT WHITE CORAL	**28**	**1048**
Soapstone-like rock	20	1068
Brown clay and BROKEN CORAL	110	1178
Hard blue lava	45	1223
Black and red clay	28	1251
Brown lava	249	1500

The well went down 1178 feet before reaching the solid lava of the bottom. In its upper part it passed through 270 feet of tufa, indicating that the tufa-cone extended below the sea-level to this depth, and therefore had a total height of over 1000 feet. Below the tufa, between the 320-foot and 825-foot

levels, there are 505 feet of *hard coral rock;* and then on the 1045-foot level, a 28-foot layer of *soft white coral* and at a greater depth, brown clay and broken coral. As the well is close by the west foot of the Head and passes through so much of its tufa, it is quite certain that the 505-foot stratum of limestone was made before the tufa-eruption; and that the beds underneath it mark earlier conditions over the site.

As regards a supply of fresh water the well was a failure—an exception to the usual experience. The water came up salt and a much stronger brine than sea-water. It was under some pressure, as it stood a foot above the level of surface wells near by.

Other borings have been made in Waikiki—the sea-border district just west of Diamond Head. The section afforded by the deepest of the Waikiki wells is here inserted for comparison. It is that of the King's well, No. 2—about half a mile west of Diamond Hill and 350 yards from the seashore.

	Thickness.	Depth.
Sand and coral	38 feet	....
WHITE CORAL ROCK	**22**	**60**
Yellow sand	43	103
Hard lava	47	150
WHITE CORAL ROCK	**110**	**260**
Blue clay	25	285
Tough clay and CORAL	65	350
Blue clay	30	380
HARD CORAL ROCK	**40**	**420**
SOFT CORAL	**30**	**450**
Tough clay	5	455
WHITE CORAL ROCK	**40**	**495**
Tough clay	30	525
WHITE CORAL ROCK	**100**	**625**
Tough clay	5	630
CORAL and clay	**70**	**700**
Tough clay	28	728
Black sand	2	730
Lava	120	850

In this well, the upper 320 feet probably correspond approximately to the upper tufa-made portion of the preceding. It is remarkable that tufa is wholly absent, although the distance from the active vent was so small; but this is accounted for by the direction of the trade winds, which would have carried the ejected material seaward—the direction in which the hill is elongated. Moreover the tufa-cone although 1000 feet high may have been thrown up in a single year or less. Instead of tufa for the upper part, there are, underneath 38 feet of sand and

coral, 22 feet of white coral rock; 110 feet more of the coral rock above the 260-foot level, and 65 feet of "tough clay and coral" next above the 350-foot level. Further, beginning with the 385-foot level, coral rock is continued to the 700-foot level, or for 315 feet, with the exception of 40 feet of clay divided between three layers; and this 315-foot layer of limestone appears to correspond to the 505-foot layer between 320 and 825 feet in the other section. The solid lava-stream of the bottom of the well was reached at 730 feet. The amount of water obtained proved that the lava-stream was one of those from the mountain. It is overlaid by 2 feet of volcanic sand and 28 of tough clay, the sand serving to contain the water and the clay to confine it, conditions suited to make the well a success.

In these sections the intercalated beds of so-called "clay" vary widely in position and thickness, and appear to be, in general, local deposits from mountain streams, or tufa deposits from one source or another. In another boring in Waikiki, a bottom of solid lava was reached at 375 feet; and in a third, Goo Kim's well, at 475 feet. The former had an intercalated lava-stream at a depth of 206 feet, and the other at 150 feet. In Goo Kim's well, which was nearly a mile from the seashore, there were 26 feet of coral rock above the 150-foot level, and 194 feet of coral rock above the 430-foot level but with two intercalations of a 20-foot layer of "clay" in the stratum. The facts as to the varying levels of the "clay" beds and the intercalation of lava-streams show what accidents the living species of the sea and its reefs were exposed to. They make the existence of a *continuous* 505-foot stratum of coral limestone underneath the tufa of Diamond Head the more remarkable.

The artesian wells made within the limits of the city of Honolulu might be expected to throw light on the history of Punchbowl.

1. A well in "Thomas Square," just south of Punchbowl, afforded the following section.

Soil 6 feet, with 6 of black sand and "clay" 4	16 ft.	---
White coral rock	200	216 ft.
Brown clay	44	260
Coral rock	10	270
Brown clay	60	330
White coral rock	50	380
Brown clay	80	460
Bed rock or lava, penetrated	49	509

2. In "Mr. Ward's well," below Thomas Square, on King street, there were at the top 15 feet of loam and sand, then 180 feet of "hard coral rock," carrying the depth to 195 feet; again 24 feet of coral and shells above the 219-foot level; and

then, underneath 109 feet of "yellow clay" which may be Punchbowl tufa, 23 feet of coral rock above the 393-foot level, and 107 feet of white and yellow sand below it; with the bottom lava at 508 feet covered by 4 feet of quicksand. An abundant flow of water was obtained.

3. South of the last, in the "Kewalo well," begun near the sea-level, beneath 6 feet of black volcanic sand, there were 50 feet of coral rock over a 40-foot layer of hard lava; then 190 feet of coral, divided in two by an intercalated 30-foot layer of "clay," over the 350-foot level; with the bottom lava-bed at 620 feet.

4. Section from a well in the Palace yard:

Soil 4 feet, black sand 4	8 feet.	...
Coral rock	64	72 feet.
Hard lava	6	78
White coral rock	60	138
Clay	240	378
Coral rock	75	452
Clay and gravel	254	707
Lava or bed rock penetrated	55	762

Of the above sections 1, 2 and 3 have a thick bed of clay on the 260-foot to 280-foot level; 1, 2 and 4 on the 330-foot, 370-foot and 378-foot levels; 1 and 2 and 3 on 460-foot, 500-foot and 535-foot levels; and No. 4, a layer 254 feet thick on the 707-foot level or the bottom rock. It is possible that one or more of these of "clay" may be decomposed tufa of Punchbowl origin. But to refer all to this source would make the period of eruption of very improbable length. The "black sand" below the soil in Honolulu is naturally referred to this source. But more investigation is required for a decision. There is no evidence that Diamond Head and Punchbowl were of simultaneous origin.

5. *West Oahu.*—The mountains of West Oahu cover at the present time a much smaller area than those of East Oahu. Their original dimensions we have no data for estimating. The highest peak, Kaala, in the northeast part of the group of summits, has a height, according to the government survey, of 3586 feet—which is 681 feet greater than that of Konahuinui; and besides this, there are, in the southeastern part, peaks of 3105 and 3110 feet. These elevations, and the deep and open valleys divided off by sharp ridges, are sufficient evidence that the mountain range is but a small remnant of the once great volcanic mountain, probably a loftier mountain than that of East Oahu. Denudation has had a far longer time for its dissecting work, and has done much to diminish the area it covers. Whether great loss has resulted also from subsidence is not ascertained.

The fact that the volcano of East Oahu was in full action long after the extension of the western cone, is shown (as I first observed in 1840 and again in 1887) by the encroachment of the eastern lava-streams over its base, and the burial in part of the valleys. The accompanying sketch is a view, looking westward from the plain made by the encroaching lavas, showing how the lavas dammed up the already made valleys of West Oahu, and forced the drainage waters to take a north or south direction, nearly parallel with the base of the mountain, in order to reach the sea. The courses of these streams are shown on the map. The depth of burial by the East Oahu lavas was probably some hundreds of feet.

1.

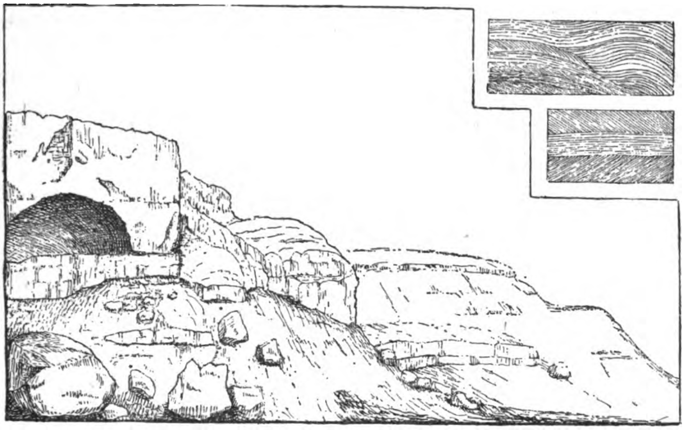
2. *Evidence of recent change of level.*

1. *Elevation.*—Evidence of recent upward change of level is afforded by the elevated coral reef along the sea-border. The dotted line on the map (Plate 4) has already been pointed to as approximately the inner limit of the raised reef; the small dotted areas about Kahuku Point, the prominent north cape of the island, and in Laie, the district next southeastward, besides others west of Waimanalo, are the positions of hills or bluffs made of the reef rock and consolidated drift sands. The rock is in some parts a beautiful white, fine-grained building stone; but generally it has sudden transitions in texture and firmness, and much of it is a consolidated mass of broken corals, or else of standing corals made compact or nearly so with coral sand. Along southern or southwestern Oahu the height of the reef is fifteen to thirty feet; and I estimated the amount of elevation indicated by it in 1840 at 30 to 40 feet.

At the Kahuku bluffs, which I visited anew in 1887 (see figure 2), the solid coral reef rock extends up in some places to a height by estimate of fifty to sixty feet above tide level; and this is surmounted by drift-sand rock, made of beach coral sands that were drifted into hills on the coast when the reef-rock was submerged, adding twenty feet or more to the height. There are large caverns in the bluffs, which are mostly within the upper layer of the coral reef-rock and have the drift-sand rock as the roof. In the sketch, a faint horizontal line may be seen passing by the top of the cavern; it separates the beds of different origin. The coral reef-rock consists mostly of cemented masses and branches of corals of the kinds common in

the modern reef, and also has often the corals in the positions of growth. But the wind-drift beds show the quaquaversal or variously-striking dip common in wind-made drifts, as represented in the two sections below.

2.



Kahuku bluffs of coral rock and drift-sands, with two sections of the drift-sand rock.

The change of level along northern Oahu, according to the facts from Kahuku, appears to have been at least sixty feet, or twenty feet greater than on its southern side. Even with an accurate measurement of the height of the reef-rock about Oahu the amount of elevation would remain doubtful because the coral reefs off the island are at present nowhere up to low-tide level; and this may or may not have been the fact before the change of level took place.

The surface of the elevated reef of Oahu is exceedingly uneven from unequal construction and erosion, and its interior has in some places large and winding caverns, so that an overlying formation, were there one, would afford an example of *unconformability by denudation.* It is obvious that with greater elevation, the unevenness would be as much greater, large enough to get the credit, perhaps, of representing an interval of many thousands of years, although results of the "modern" period in geology. Denudation works rapidly among limestones and especially so when the limestones have just left the water, with the usual irregularities of upper surface and texture.

2. *Subsidence.*—A gradual subsidence of the island is apparently indicated by the coral reefs, through the depth to which they have been found to extend in Artesian borings. In these borings, described on page 96, a depth of 700 to 800 feet was

found for the coral rock, and more than 1,000 for broken corals; and over 700 is reported by Mr. McCandless from a well in the Eua district, about five miles west of Honolulu. The facts lead to the inference that the subsidence amounted to at least 800 feet, and that it corresponds to the coral-reef subsidence which Darwin's theory requires. Mr. McCandless informed me that fragments of corals like those of the modern reefs were brought up from the various levels.

This evidence of subsidence to the amount stated is not, however, complete. Doubt remains because the corals brought up in fragments have not been examined by any one competent to decide on their actual identity with existing species; I could not find that any of them had been preserved. The importance of their preservation and careful study is now understood, and we may hope before long to have the doubt removed. As the case stands, the *probability* is that the limestone is to the bottom true coral-reef rock and that the depth to which it extends is, therefore, a measure of actual subsidence.

Darwin's Coral Island theory.—In the above statements the present condition of Darwin's theory of Coral Islands, is fully and fairly recognized. Much has been recently written about the theory's having been set aside or proved to be without foundation. But in truth, no facts have been published that prove the theory false, or set aside the arguments in its favor. The facts and arguments from Tahiti brought out by Mr. Murray I have shown, in my review of the subject in this Journal in 1885* (published also at the same time in the London Philosophical Magazine), to have no weight and more than this, to sustain Darwin's theory, instead of opposing it. The idea of the excavation of the lagoon-basins of coral islands by sea-waters I have also proved in the same paper to be not a possibility.

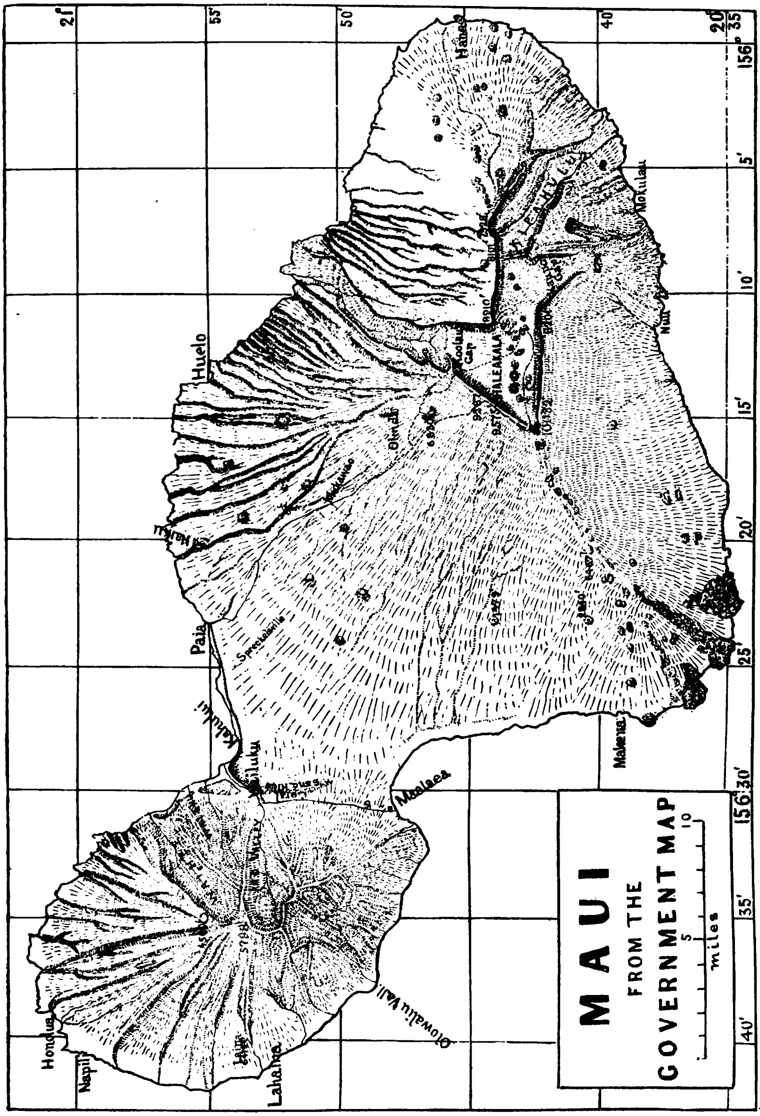
The only suggestion of real importance that has been presented is not against Darwin's explanation, but simply in favor of a possible substitute. Mr. A. Agassiz and others have suggested that deep-sea organisms may build up limestone over the sea-bottom, and thus raise the rock to the level where reef-forming corals may grow, or within 100 to 150 feet of the surface; and that, in this way, coral reefs and islands *may* have been formed without subsidence. Mr. Guppy has shown that some coral-made limestone, in the southwest Pacific, actually has a base of limestone that had been made by other life than that of reef-corals. This is all the foundation for setting aside Darwin's conclusions. It is good ground for doubting, and a good reason for investigating the nature of the coral limestone in the various coral-reef regions of the Pacific at

* Volume xxx, pp. 89 and 169.

depths below the level of 100 to 150 feet—as I state in the article referred to, where I propose that deep borings should be made, under government authority, on a sufficient scale to settle the question. The borings have been made on Oahu; but, as I say above, the fossils of the reef-rock passed through below the coral-growing limit have not been examined and the subsidence therefore is not positively proved. There are many collateral arguments in favor of the Pacific coral-island subsidence reviewed in my paper which still remain strong; but they may be held in abeyance until the borings have been satisfactorily made. These and other points are discussed at length in the paper to which I have above referred.

I took no part in the controversy with reference to the statements of the dogmatic Duke of Argyll, knowing that the subject was in good hands. But I may here say that the charge which he made that no one had dared to bring forward and discuss the facts and views published by Mr. Murray and others against Darwin's theory was the more inexcusable that my paper had appeared as recently as in 1885 in the London Philosophical Magazine. The charge was based on ignorance of the facts on all sides, and on incapacity to appreciate the spirit actuating men of true science.

One other paper—on the question *whether volcanic action is a cause or not of trough-making over the Ocean's bottom, with a review of the ocean's depths illustrated by a new bathymetric chart*—will close this series with the exception of the promised paper on the rocks of the islands by E. S. Dana.



MAUI
FROM THE
GOVERNMENT MAP
miles
Huelo
Paia
Wailuku
Maalaea
Lahaina
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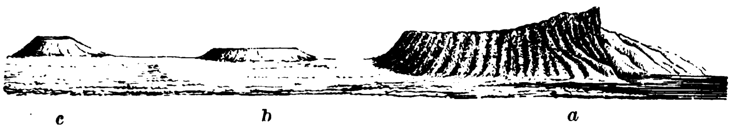
Napili
Makena
Mokulau
HALEAKALA

1



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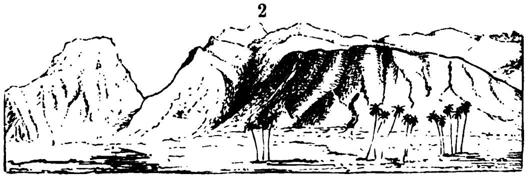

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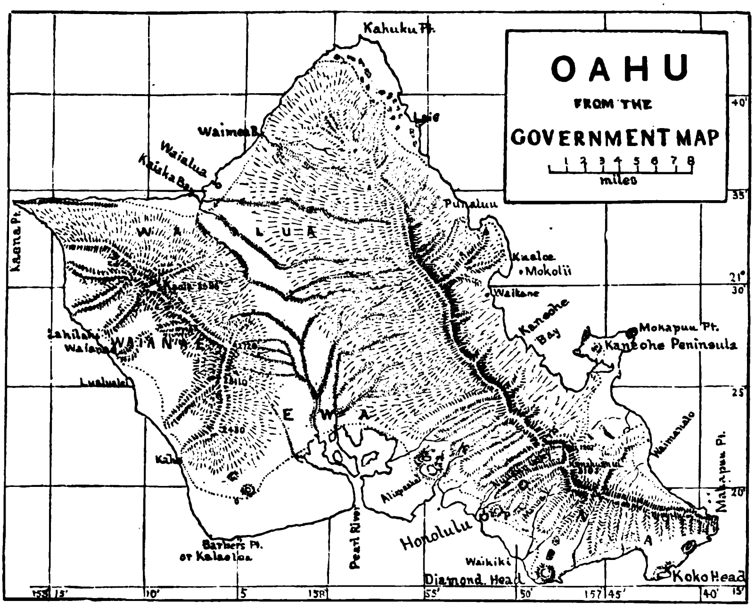

1. The volcanic cones: *a*, Diamond Head, or Leahi; *b*, Kaimuki, or Telegraph Hill, and *c*, Maaumae. 2. Punchbowl, or Puowaina, with Nuuanu valley to the left, and the peaks Konahuanui and Lunahili, right and left of the pali. 3. The Koko Head craters.

[From the American Journal of Science, Vol. XXXVII, March, 1889.]

ON THE ORIGIN OF THE DEEP TROUGHS OF THE OCEANIC DEPRESSION: ARE ANY OF VOLCANIC ORIGIN?

By James D. Dana.

ART. XXII.—*On the Origin of the deep troughs of the Oceanic depression: Are any of Volcanic origin?* by JAMES D. DANA, with a bathymetric map, Plate VII.

THE consideration of the question with regard to the origin of the ocean's deep troughs requires, as the first step, a general review of oceanic topography; for according to recent bathymetric investigations, the deep troughs are part of the system of topography, and its grander part. We need, for this purpose, an accurate map of the depths and heights through all the great area. Such a map will ultimately be made through the combined services of the Hydrographic Departments of the civilized nations. At the present time the lines of soundings over the oceans, especially over the Pacific and Indian, are few, and only some general conclusions are attainable. It is to be noticed that the system of features of the oceanic area are involved in the more general terrestrial system; but since the former comprises nearly three-fourths of the surface of the sphere, it is not a subordinate part in that system.

With reference to this discussion of the subject I have prepared the accompanying bathymetric map.

I. THE BATHYMETRIC MAP, AND THE GENERAL FEATURES OF THE OCEANIC DEPRESSION DISPLAYED BY IT.

1. *The Map.*—In the preparation of the bathymetric map I have used the recent charts of the Hydrographic Departments of the United States and Great Britain,* which contain all depths to date, and the lists of new soundings published in German and other geographical Journals. In order that the facts on which the bathymetric lines are based may be before the reader a large part of the depths are given, but in an abbreviated form, 100 fathoms being made the unit: 25 signifying 2500 fathoms or nearly (between 2460 and 2550); 2·3, about 230 fathoms, ·4, about 40 fathoms. Only for some deep points is the depth given in full. The addition of a plus sign (+) signifies no bottom reached by the sounding.†

* I am indebted to the Hydrographic Departments of Great Britain as well as the United States for copies of these charts.

† On the map the bathymetric lines for 1000, 2000, 3000 and 4000 fathoms, besides being distinguished in the usual way by number of dots, have been made to differ in breadth of line, the deeper being made quite heavy in order to exhibit plainly the positions of the areas without the use of colors. The line for 100 fathoms is, as usual, a simple dotted line. As the bathymetric map herewith

In the plotting of oceanic bathymetric lines from the few lines of soundings that have been made, the doubts which constantly rise have to be settled largely by a reference to the general features of the ocean, and here wide differences in judgment may exist in the use of the same facts; but through the depths stated on the map, the reader has the means of judging for himself. In the case of an island the lines about it may often have their courses determined by those of adjoining groups, or by its own trend; but in very many cases new soundings are needed for a satisfactory conclusion.

Some divergences on the map from other published bathymetric maps require a word of explanation. The northern half of the North Pacific is made, on other deep-sea maps, part of a great 3000-fathom area (between 3000 and 4000) stretching from the long and deep trough near Japan far enough eastward to include the soundings of 3000 fathoms and over in mid-ocean along the 35th parallel. It has seemed more reasonable, in view of present knowledge from soundings, to confine the deep-sea area off Japan to the border-region of the ocean, near the Kurile and Aleutian islands, and leave the area in mid-ocean to be enlarged as more soundings shall be obtained. Again in the South Pacific, west of Patagonia, the area of relatively shallow soundings (under 2000 fathoms) extending out from the coast, is on other maps bent southward at its outer western limit so as to include the area of similar soundings on the parallel of 40° and 50°, between 112° and 122° W. The prevailing trends of the ocean are opposed to such a bend, and more soundings are thought to be necessary before adopting it.

It may be added here that in the Antartic Atlantic, about the parallel of 66½° S. and the meridian of 13½° W., a large area of 3000 and 4000 fathoms has been located. It was based, as I have learned from the Hydrographic Department of the British Admiralty, on a sounding in 1842 by Capt. Ross, R. N., in which the lead ran out 4000 fathoms without finding bottom. The sounding was, therefore, made before the means

published is necessarily small, and none of the ordinary maps of the oceans give either deep-sea soundings or a correct idea of the trends of the oceanic ranges of islands, I state here that the charts of the U. S. Hydrographic Department for the Atlantic, Pacific, Indian and Arctic oceans may be purchased of dealers in charts in the larger sea-board cities for 50 cents a sheet and less according to size. (There are several large charts to each ocean). One of the firms selling them in New York City is that of T. S. & J. D. Negus, 140 Water st. The British Admiralty have published a map of the Pacific with its soundings on a single sheet, and for the Atlantic and Indian oceans with part of the Pacific, besides charts of the Antarctic and Arctic seas. The occasional bulletins from the Hydrographic Department and Petermann's Mittheilungen contain nearly all the new data issued for the perfecting of such a chart.

available were "sufficient to ensure the accuracy of such deep casts."*

2. *The Feature-lines of the oceanic and bordering lands.*—The courses of island-ranges and coast-lines have a bearing on the question relating to the courses of the deep-sea troughs, and, therefore, by way of introduction, they are here briefly reviewed.† The system of trends in feature-lines takes new significance from a bathymetric map, for the courses are no longer mere trends of islands or emerged mountain peaks; they are the trends of the great mountain ranges themselves; and, in the Pacific, these mountain courses are those of half a hemisphere. Some of the deductions from such a map are briefly as follows:

(1). Over the Pacific area there are *no* prominent north-and-south, or meridional, courses in its ranges, and none over the Atlantic, except the axial range of relatively shallow water in the South Atlantic. And, to this statement it may pertinently be added that there are none in the great ranges of Asia and Europe, excepting the Urals; none in North America; none in South America, excepting a part of those on its west side.

(2). The ranges in the Pacific ocean have a mean trend of not far from northwest-by-west, which is the course very nearly of the longer diameter of the ocean. One *tranverse* range crosses the middle South Pacific—the New Zealand—commencing to the south in New Zealand and the islands south of it, with the course N. 35° E., and continuing through the Kermadec Islands and the Tonga group, the latter trending about N. 22° E., and this is the nearest to north and south in the ocean, except toward its western border.

(3). The oceanic ranges are rarely straight, but instead, change gradually in trend through a large curve or a series of curves. For example, the chain of the central Pacific becomes to the westward, north-northwest; and the Aleutian range and others off the Asiatic coast, make a series of consecutive curves. Curves are the rule rather than the exception. Moreover, the intersections of crossing ranges, curved or not, are in general nearly rectangular.

(4). Approximate parallelisms exist between the distant ranges or feature-lines; as (1) between the trend of the New

* The communication received from the Admiralty Office adds that "Some of Ross's soundings up to 2660 fathoms have been proved correct, and hence the sounding in 68° S., referred to, has been retained on our charts until disproved." "Another sounding obtained by Ross in the Atlantic has had strong doubts thrown upon it by a sounding of 3000 fathoms obtained not very far from its position." See the accompanying map, near latitude 14° S.

† This subject of the system in the earth's feature-lines is presented at length, with a map, in my Expedition Geological report, pp. 11–23 and 414–424; and also more briefly in this Journal, II, ii, 381, 1846.

Zealand range and that of the east coast of North America; and also that of South America (which is continued across the ocean to Scandinavia); also (2) between the trend of the foot of the New Zealand boot with the Louisiade group and New Guinea farther west, and the mean trend of the islands of the central Pacific both south and north of the equator, and also that of the north shore of South America. These are a few examples out of many to be observed on the map.

(5). The relatively shallow-water area which stretches across the North Atlantic from Scandinavia to Greenland—the Scandinavian plateau, as it may well be called—is continued from these high latitude seas southwestward, in the direction of the axis of the North Atlantic (or parallel nearly to the coast of eastern North America and the opposite coast of Africa), and becomes the "Dolphin shoal."

It may be a correlate fact in the earth's system of features that a Patagonian plateau stretches out from the Patagonia coast, or from high southern latitudes, in the direction of the longer axis of the Pacific, and embraces the Paumotu and other archipelagos beyond.*

The above review of the Earth's physiognomy, if accompanied by a survey of the map, may suffice for the main purpose here in view: to illustrate the general truths—that system in the feature-lines is a fact; that the system is world-wide in its scope; and—since these feature-lines have been successively developed with the progress of geological history—that the system had its foundation in the beginning of the earth's genesis and was developed to full completion with its growth.

2. Facts Bearing on the Origin of the Deep-sea Troughs.

In treating of this subject, the facts from the vicinity of volcanic lands that favor a volcanic origin are *first* mentioned;

* As parallelisms may have importance that is not now apparent, I draw attention to one between the Mediterranean Sea that divides Europe from Africa, and the West India (or West Mediterranean) sea that divides North from South America. Both have an *eastern*, *middle* and *western* deep basin. Their depths (see map) in the East Mediterranean, are 2170, 2040 and 1585 fathoms; in the West Mediterranean (the three being the Caribbean, the West Caribbean or Cuban, and the Gulf of Mexico), 2804, 3428 and 2080 fathoms. Further, in each Mediterranean Sea, a shallow-water plateau extends from a prominent point on the south side, northward, to islands between the eastern and middle of the deep basins; one from the northeast angle of Tunis to Sicily, the other from the northeast angle of Honduras to Jamaica and Haiti, the two about the same in range of depth of water. And this last parallelism has its parallels through geological history, even to the Quaternary, when the great Mammals made migrations to the islands in each *from the continent to the South.*

secondly, those from similar regions that are not favorable to such an origin; *thirdly*, facts from other regions bearing on the question.

A. *Facts apparently favoring a volcanic origin.*

1. The Pacific soundings have made known the existence of two deep-sea depressions, if not a continuous trough, *within forty miles of the Hawaiian Islands;* one situated to the northeast of Oahu, or, north of Molokai, with a depth of 3023 fathoms, or 18,069 feet, and the other east of the east point of Hawaii, 2875 fathoms, or within 750 feet of 18,000 feet. Again, 450 miles northeast of Oahu, there is a trough in the ocean's bottom, over 800 miles long, which runs nearly parallel with the group and has a depth of 3000 to 3540 fathoms; and, as far south, another similar trough of probably greater length has afforded soundings of 3000 to 3100 fathoms. The depths about the more western part of the Hawaiian chain of islands have not yet been ascertained, and hence the limits of the deep areas are not known. Such depths, so close to a line of great volcanic mountains, the loftiest of the mountains not yet extinct, appear as if they might have resulted from a subsidence consequent on the volcanic action.

The subsidence might have taken place (1) either from underminings:—which the amount of matter thrown out and now constituting the mountain chain, with its peaks of 20,000 to 30,000 feet above the sea-bottom, shows may be large; or (2) from the gravitational pressure in the earth's crust, about a volcanic region which speculation makes a source of the ascensive force and of the upward rising of the lavas,—the subsiding crust following down the liquid surface beneath. In either case the mass of ejected material might be a measure more or less perfectly of the maximum amount of subsidence.

2. In the western part of the North Pacific, at the south end of the volcanic group of the Ladrones off the largest island of the group, Guam, the Challenger found a depth of 4475 fathoms, one of the two deepest spots yet known in the Pacific. The situation with reference to the group is like that off the east end of the Hawaiian group.

3. East of Japan and the Kuriles, a region of ranges of volcanoes, there is the longest and deepest trough of the ocean, the length 1800 miles, the depths 4000 to 4650 fathoms; and farther northeast, south of one of the Aleutian islands, a depth of 4000 fathoms occurs again; and depths of 3100 to 3664 fathoms also still farther east. It is probable that the 4000-line trough continues from the Kurile to this deep spot off the Aleutian volcanic range; and if so, the length of the trough

is over 2500 miles. The map is made to suggest its extension still farther eastward; but among the very few soundings made, none below 3664 fathoms have yet been obtained off the more eastern Aleutians.

Other similar facts may be found on the map; and still others may exist which are not now manifest owing to the sinking of oceanic areas and islands. But no cases can be pointed to which are more decisively in favor of volcanic origin.

B. *Facts from the vicinity of volcanic regions apparently not referable to a volcanic origin.*

1. The ocean off the western border of North and South America affords striking examples of the absence of deep troughs from the vicinity of regions eminently volcanic. The South American volcanoes are many and lofty; and still the ocean adjoining is mostly between 2000 and 2700 fathoms in depth; and just south of Valparaiso, it shallows to 1325 fathoms. The only exception yet observed is that of a short trough of 3000 to 3368 fathoms close by the Peruvian shore. It may, however, prove to be a long trough, although certainly stopping short of Valparaiso. The waters, however, of the Pacific border of America deepen abruptly compared with those of the Atlantic border; and the significance of this fact deserves consideration.

The facts off Central America are more remarkable than those off the coast to the south. The volcanoes are quite near to the Pacific coast, and still the depths are between 1500 and 2500 fathoms.

The condition is the same off the west coast of North America. Of the two areas of 3000 and over, nearest to the east coast of the North Pacific, one is 600 miles distant in the latitude of San Francisco, and the other is within ten degrees of the equator and twenty degrees of the coast; both too far away to be a consequence of volcanic action in California, Mexico or Central America.

In the North Atlantic the European side has its volcanoes and has had them since the Silurian era, and yet the non-volcanic North American side of the ocean has far the larger areas of deep water and much greater mean depth. The Azores or Western Islands, which are all volcanic, have depths around them of only 1000 to 2000 fathoms and no local troughs. Iceland, the land of Hecla, is in still shallower waters, with no evidence of local depressions off its shores. The Canaries are volcanic, but no deep trough is near them.

C. *Facts from regions not volcanic which are unfavorable to the idea of a volcanic origin.*

1. In the North Pacific, near its center, the area of 3000 or more fathoms about 35° N.; the two similar but smaller areas toward its eastern border; the areas north of the Carolines in the western part of the ocean; the broad equatorial area about the Phœnix Group; the area in the South Pacific in 170° W., east of Chatham Island, and another just south of Australia, are all so situated that no reason is apparent for referring them to a volcanic origin. Some of the areas are in the coral-island latitudes, and the supposed volcanic basis of coral-islands makes a volcanic origin possible, but their probable size and position appears to favor the idea of origin through some more fundamental cause. The area in the South Pacific, east of Chatham Island, is 450 miles distant from the land. The border of southern Australia, abreast of the deep-sea trough, has no known volcano.

2. *In the Atlantic, away from the West Indies*—The 3000-fathom areas of the North and South Atlantic, that is, the three in the North Atlantic, the two in the South Atlantic, and the two equatorial, one near the coast of Guinea and the other near that of South America, occupy positions that suggest no relation to volcanic conditions. The Cape Verdes, north of the equator, are partly encircled by one of the deep areas, somewhat like the eastern end of the Hawaiian group; but this bathymetric area appears to be too large to owe its origin directly to volcanic work in the group. The coast of Guinea near the 3000-fathom area has nothing volcanic about it, and the opposite coast of South America, near another, is free from volcanoes.

The only facts in the Atlantic that suggest a volcanic origin are the depression of 2445 fathoms within 40 miles of the west side of the volcanic Cape Verde Archipelago, and that of 2060 fathoms within 20 miles of Ascension Island; and a connection is possible.

3. *In and near the West Indies.*—The most remarkable of the depths of the Atlantic area are situated in and near the region of the West Indies, as is well illustrated and discussed by Mr. Alexander Agassiz in his instructive work on the "Three Cruises of the Blake." The deepest trough of the ocean, 4561 fathoms, occurs within seventy miles of Porto Rico; and yet this island has no great volcanic mountain, though having basaltic rocks. By the north side of the Bahama belt of coral reefs and islands, for 600 miles, as Mr. Agassiz well illustrates, the depth becomes 2700 to 3000 fathoms within twenty miles of the coast-line, and at one point 2990 within twelve miles, a pitch-down of 1 : 3·5; and nothing suggests a volcanic cause for

the abrupt descent. Cuba and Hayti are not volcanic, and look as if they were an extension of Florida, so that no grounds exist for assuming that the Bahamas rest on volcanic summits.

One of the strangest of 3000 fathom troughs is that which commences off the south shore of Eastern Cuba, having there a depth of 3000 to 3180 fathoms. It is within 20 miles of this non-volcanic shore, and nearly three times this distance from Jamaica. No sufficient reason appears at present for pronouncing its origin volcanic. It is continued in a west-by-south direction to a point beyond the meridian of 85° W. or over 700 miles, making it a very long trough, and the depths vary from 2700 to 3428 fathoms. The depression extends on into the Gulf of Honduras, carrying a depth of 2000 fathoms far toward its head, and in a small indentation of the coast it stops; for nothing of it appears in the outline of the Pacific coast or the depths off it, and nothing in the range of volcanic mountains on the coast. Against the three deepest parts of the trough there are, *first*, the Grand Cayman reef, 20 miles north of a spot 3428 fathoms deep; *second*, banks in 13 and 15 fathoms within 15 miles of a depth of 2982 fathoms; and *third*, Swan Island reef, 15 miles south of a depth of 3010 fathoms; the first of the three indicating a slope to the bottom of 1 : 5, and the last of 1 : 4·4. Why these greatest depths in the trough, so abrupt in depression, should be on one side of shoals or emerged coral reefs, it is not easy to explain; and the more so that the part of the trough south of Cuba has nothing volcanic near by in the adjoining mountain range, and the fact also that the westernmost end of the trough extends on for 175 miles, and there has a depth of 3048 fathoms, with 2000 fathoms either side and no coral reefs.

D. *Arrangement of the deep sea troughs in the two halves of the oceans, pointing to some other than a volcanic origin.*

The *western* half of the Atlantic and Pacific oceans contains much the larger part of the 3000-fathom areas and all the depths over 4000 fathoms. In the North Atlantic the areas of 3000 and over in the western half, or off the United States, are very large; and the bathymetric line of 2500 fathoms extends westward nearly to the 1000-fathom line. This important feature can be appreciated for both oceans from a look at the map without special explanations.

As a partial consequence of this arrangement, the Pacific, viewed as a whole, may be said to have a westward slope in its bottom, or from the South American coast toward Japan. This westward slope of the bottom exists even in the area between

New Zealand and Australia—the ocean in this area being shallow for a long distance out on the east side and deepening to 2500–2700 fathoms close to that non-volcanic land, New South Wales, in eastern Australia. In the Atlantic, the slope is in the direction of its northeast-southwest axis, either side of the Dolphin shoal, but especially the western side, rather than from east to west, it commencing in the Scandinavian plateau and ending in the great depths adjoining the West Indies.

Owing to the system in the Atlantic topography, the Dolphin Shoal—the site of the *Atlantis* of ancient and modern fable—is really an appendage to the eastern continent, that is to Europe, and is shut off by wide abyssal seas from the lands to the west that have been supposed to need its gravel for rock-making.

But the view that the west half of an oceanic basin is always the deepest becomes checked by finding in the Indian ocean that the only areas that are 3000 fathoms deep or over are in the *eastern* part of the ocean and off the northwest coast of Australia, and near western Java and Sumatra. The greatest depths in its western half or toward Africa, are 2400 to 2600 fathoms.*

3. Conclusions.

1. The facts reviewed lead far away from the idea that volcanic action has been predominant in determining the position of the deep-sea troughs. It has probably occasioned some deep depressions within a score or two of miles of the center of activity, but beyond this the great depths have probably had some other origin.

2. It is further evident that the deep-sea troughs are not a result of superficial causes of trough-making. Erosion over the ocean's bottom cannot excavate isolated troughs. The coldest water of the ocean stands in the deep holes or troughs instead of running, as the reader of Agassiz's volume has learned.

The superficial operation of weighting the earth's crust with sediment, or with coral or other organic-made limestone, and filling the depressions as fast as made, much appealed to in explanations of subsidence, has not produced the troughs; for filled depressions are not the kind under consideration. More-

* In the Arctic seas, going north from the Scandinavian plateau, the water deepens north of the latitude of Iceland, between Greenland and Spitzbergen, to 2000 fathoms, and farther north to 2650 fathoms, in the latitude nearly of Greenwich; and it is probable that the 2000-fathom area extends over the region of the North Pole. The continents of Europe (with Asia probably) and North America, are proved by the shallow soundings over the adjoining Arctic seas and the islands or emerged land, to extend to about 82½° N., which is about 450 miles from the pole.

over, the areas are out of the reach of continental sediments and too large and deep to come within the range of possibilities of organic sedimentation or accumulation. The existence of the troughs is sufficient proof of this. The deep troughs of the West Indian and adjoining seas are in a region of abundant pelagic and sea-border life, and yet the marvelous depths exist. And the depths of the open oceans are no less without explanation. Those close by the Bahamas extending down to 16,000 and 18,000 feet, are evidence of great subsidence from some cause; and the coral reefs for some reason have manifestly kept themselves at the surface in spite of it.*

3. If superficially acting causes are insufficient, we are led to look deeper, to the sources of the earth's energies, or its interior agencies of development, to which the comprehensive system in its structure and physiognomy points. Whatever there is of system in the greater feature lines, whether marked in troughs or in mountain chains, or island ranges, must come primarily from systematic work within. The work may have been manifested in long lines of flexures or fractures as steps in the process, but the conditions which gave directions to the lines left them subject to local causes of variation, and between the two agencies, the resulting physiognomy has been evolved.

We have from the Pacific area one observation of a volcanic nature bearing on the comprehensiveness of the system of feature-lines in the oceans, and although I have already referred to it, I here reproduce the facts for use in this place.

If the ranges of volcanic islands were, in their origin, lines of fissures as a result of comprehensive movements, the lines should continue to be the courses of planes of weakness in the earth's crust. The New Zealand line, including the Kermadec Islands and the Tongan group, has been pointed to as one of these lines, and one of great prominence, since it is the chief northeastward range of the broad Pacific, and nearly axial to the ocean. The series of volcanoes along the axis of New Zealand is in the same line. It was noticed, at the Tarawera eruption of 1883, that *four or five days after* the outbreak, and three after it had subsided, White Island, in the Bay of Plenty, at the north end of the New Zealand series, became unusually active; and *two months later* there was a violent eruption in the Tonga group, on the Island of Niuafou. The close relation in time of the latter to the New Zealand erup-

* The migrations from South America alluded to in a note to page 195, proving an elevation of 2000 feet to make it possible, prove also that a large part of the West India seas *afterward* suffered subsidence in the Quaternary. How far the Bahama and Florida region participated in the subsidence is not known. That it did not participate in it has not been proved.

tion is referred to by Mr. C. Trotter, in Nature of 1886, Dec. 7.* May it not be that these disturbances were due to a slight shifting or movement along a series of old planes of fractures, taking place successively from south to north; and, hence, that even now changes of level may take place through the same comprehensive cause that determined the existence of the earth's feature lines? Owing to the long distance of the Tonga group from New Zealand an affirmative reply to the question cannot be positively made. But there is probability enough to give great interest to this branch of geological enquiry.

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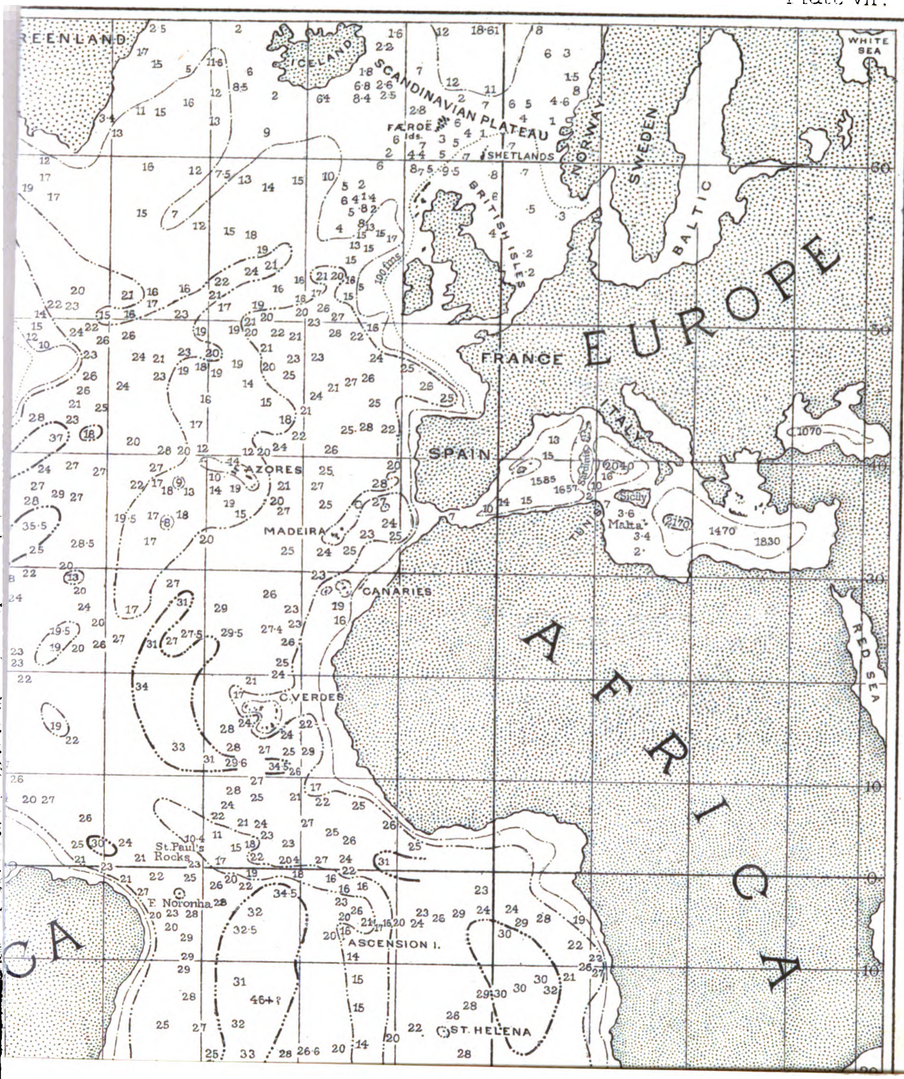
5. *Bathymetric Map, Plate VII.*—After the preceding paper was printed, I received a communication from Marshall McDonald, Commissioner of the U. S. Fish Commission, dated February 12, in which he mentioned the very interesting fact that the Albatross, of the Fish Commission, has proved the extension of the deep depression south of the eastern part of the Aleutian Islands to a distance westward of about 400 miles. In crossing it a depth was obtained, in Lat. 52° 20′ N. and Long. 165° 00′ W., of 3820 fathoms. The trough was found to be 30 miles wide. In 52° 18′ N. and 163° 54′ W., the depth found was 2848 fathoms, in 52° 20′ N., 166° 05′ W., 2654 in 52° 40′ N., 166° 35′ W., 2267 fathoms, in 52° 53′ N., 166° 44′ W., 1961 fathoms. The direction obtained for the deep trough was S. 65° W. The conclusion is stated that "The soundings revealed a depression only" and not a continuation of the trough "to the Tuscarora's soundings of 4037 fathoms off Attou." J. D. D.

* This Journal, III, xxxiii, 311.

Plate VII.


GREENLAND
ICELAND
SCANDINAVIAN PLATEAU
FÆROE Ids.
SHETLANDS
NORWAY
SWEDEN
WHITE SEA
BALTIC
BRITISH ISLES
EUROPE
FRANCE
SPAIN
ITALY
Sardinia
Sicily
Malta
TUNIS
AZORES
MADEIRA
CANARIES
C. VERDES
AFRICA
RED SEA
St. Paul's Rocks
F. Noronha
ASCENSION I.
ST. HELENA

[FROM THE AMERICAN JOURNAL OF SCIENCE, VOL. XXXVII, JUNE, 1889.]

ART. XLVI.—*Contributions to the Petrography of the Sandwich Islands;* by EDWARD S. DANA. With Plate XIV.

THE rock specimens, the results of whose study are detailed in the following pages, were in part collected by Professor James D. Dana on his trip to the Sandwich Islands in August, 1887, and the remainder by the Rev. E. P. Baker of Hilo in 1888. The first series includes about thirty specimens from Kilauea, a third of them from the projectile deposits on its borders; several from other points in Hawaii; about a dozen specimens from the island of Maui, chiefly from the extinct crater of Haleakala; and finally an equal number from different points on the island of Oahu. The special localities are mentioned beyond. The second series of specimens are all from Hawaii, and chiefly from Mokuaweoweo, the summit crater of Mauna Loa. There are also a few specimens from Makaopuhi and Nanawale on Hawaii, points which belong to the Kilauea region.

For our present knowledge of Hawaiian lavas we are indebted in the first place to the general descriptions of J. D. Dana in the Geology of the Exploring Expedition (1849), and W. T. Brigham in his Notes* on the Volcanoes of the Hawaiian Islands (1868); also C. E. Dutton (1884) and others. On the other hand, on the petrographical side, there have been published the microscopic study of basaltic glass of Hawaii, especially Pele's Hair, by Krukenberg† in 1877; a paper by Cohen‡ devoted chiefly to the glassy basaltic lavas of Hawaii; brief descriptions of isolated specimens of nepheline basalts believed to have come from Oahu by Wichmann§ and by Rosenbusch;‖ finally a recent memoir by Silvestri¶ describing a series of ancient and modern lavas from Kilauea collected by Prof. Tacchini in 1883.

1. *Lavas of Mauna Loa and its summit crater, Mokuaweoweo.*

For the collection of lava specimens from the summit crater of Mauna Loa, the writer is indebted, as is stated above, to the Rev. E. P. Baker.** The collection is a large one and evidently

* Mem. Boston Soc. Nat. Hist., vol. i, pt. 3.

† Mikrographie der Glasbasalte von Hawaii, petrographische Untersuchung von C. F. W. Krukenberg, Tübingen, 1877.

‡ Jahrb. Min., vol. ii, 23, 1880.

§ Jahrb. Min., 172, 1875.

‖ Mass. Gesteine, 510, 1877.

¶ Bull. Com. Geol. d'Italia, xix, 128–143, 168–196, 1888.

** Mr. Baker's extended trip over Hawaii, which included, besides an exploration of the summit crater, a visit to the sources of several of the great lava streams, was undertaken in order to make the collections of rocks and gather facts with regard to the eruptions, and some extracts from his notes are published in this volume at p. 52. The results have proved to be of very great interest.

represents well the characteristic types of rocks. It numbers, exclusive of the "pumice" and scoria upwards of seventy specimens; of these about fifty have been subjected to microscopic study. In regard to the geographical distribution of the rocks with reference to their relative age but little can be said. A considerable part (Nos. 90–109) are from the talus within the southern crater of Mokuaweoweo against the neck between it and the central pit. (See the map in vol. xxxvi, plate II). A number of others (78–89) are from the eastern side of the central pit; and in the case of scattering specimens, the special source is mentioned more minutely beyond, when interest seems to attach to it.

In general it may be said that all the specimens in hand from Mauna Loa belong to the same class of basaltic lavas, although they vary widely: in color from dark gray to light gray or dull brick-red; in structure from compact to highly cellular or vesicular; from those of uniform grain to those which are prominently porphyritic with chrysolite or feldspar; and in composition from the very highly chrysolitic kinds to the feldspathic or augitic forms with little or no chrysolite. Specimens of pumice-like scoria are largely represented in the collection.

The specimens may be divided pretty sharply into two groups, besides which there are several other types more or less distinct from these.

Clinkstone-like basalt.—The first of these doubtless includes the rock which former observers have spoken of as resembling phonolite. Macroscopically it has a uniform fine-grained texture, for the most part free from vesicles and apparently compact, though often found on closer examination to be minutely porous. The color varies from a dark bluish gray to light gray, and to dull brick-red or brown, the grayish kinds being the most common. The specific gravity varies from 2·82 to 3·00.* Many of these specimens, as taken from the talus between the central and southern craters, are in the form of thin slabs and their resemblance to clinkstone in the hand specimen, though not going beyond external aspect, is sufficiently close to explain their having been so named. As regards composition the rocks of this type are most strongly marked by the fact that the chrysolite, which is so common in large grains in the other specimens to be described, is absent or only sparingly present.

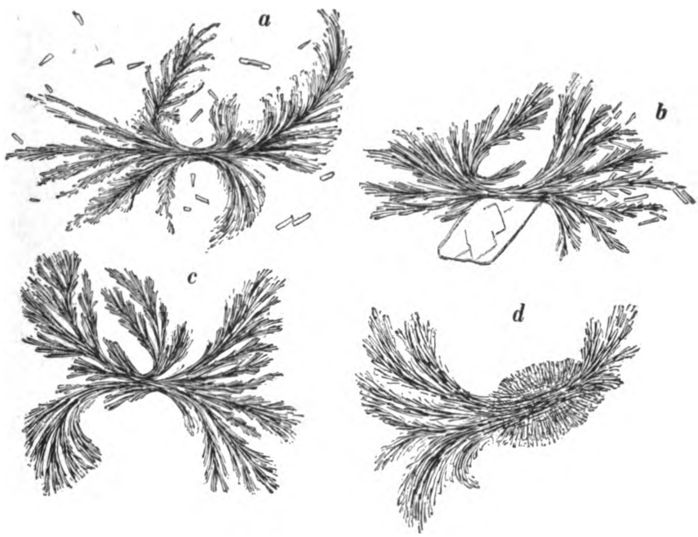
The microscopic characters of this group of fine-grained compact rocks are also such as readily to distinguish them from the other forms. In general they consist of augite and plagio-

* Some of the separate determinations on fragments freed from air by boiling are: 3·00, 2·94, 3·00, 2·87, 2·82, 3·00, 2·82.

clase, and titanic, or magnetic iron or both, prominent, but with little or no chrysolite. Their most interesting feature is the form taken by the augite, which is only exceptionally developed as an idiomorphic constituent, but on the other hand is not simply a formless substance filling the spaces between the feldspar. It is uniformly, though with varying degrees of distinctness, grouped in radiating forms, fan-shaped or feather-like, of great variety and beauty.

This structure is eminently characteristic of this group of rocks. It is shown best in a fine-grained purplish colored specimen (No. 97, G.=2·82). This is seen under the hand glass to be minutely porous though not properly vesicular, with minute slender red crystals (augite) projecting into the cavities. An occasional grain of chrysolite can be detected in the mass and cleavage sections of feldspar are also seen. Under the microscope it is made up of lath-shaped feldspar individuals and the beautiful groupings of augites, these set out in relief by the fine grains

1.



Feather-forms of augite; *a* (× 35), *b* (× 35), *c* (× 50) from Mokuaweoweo, *d* (× 70) from Kilauea.

of iron ore surrounding them. In the simplest cases the augite is bunched together in long parallel groups slightly diverging at the extremities; generally these branch off at various points into feather-like or dendritic forms, of such variety as to be

beyond description. Groups of these forms radiating from a center are common.*

The accompanying figure, 1, shows several of the more complex of these forms (*a*, *b* from this specimen) and gives a fair representation of this remarkable structure. Figure 2 gives the appearance of the entire field of the microscope, showing forms like the frost crystals occasionally seen on a stone pavement; this figure is simplified by the omission of some of the less defined parts.

Some of the simpler rosettes are made up of both feldspar and augite alike radiating from a common center; and frequently the extremities of the feather ends are feldspar individuals. Figure 3 gives a detailed drawing of part of one of

2.

Feather-augite in basalt from Mokuaweoweo. Magnified 60 times.

3.

Detailed drawing showing the feather-like grouping of augite and feldspar. Magnified 100 times.

the groups. It would seem that the feldspar was as usual first separated, and the augite as it crystallized out into these dendritic forms drew the feldspar needles into position with it. The two minerals are sometimes so intricately involved with each other that it requires close examination to separate them. In polarized light the distinction comes out more sharply.

* Mr. H. Hensoldt of New York has called the writer's attention to an augitic lava from Tahiti in which the pinkish, pleochroic augite is present in radiating groups of acicular crystals, often having a nucleus of chrysolite. The section is one of very exceptional beauty and interest, although the arrangement of the augite is hardly to be compared with that here described, since the individual crystals are sharp and geometrically grouped—after the manner of the tourmaline in luxullianite—which is in marked contrast to the feather forms of the Mauna Loa augite.

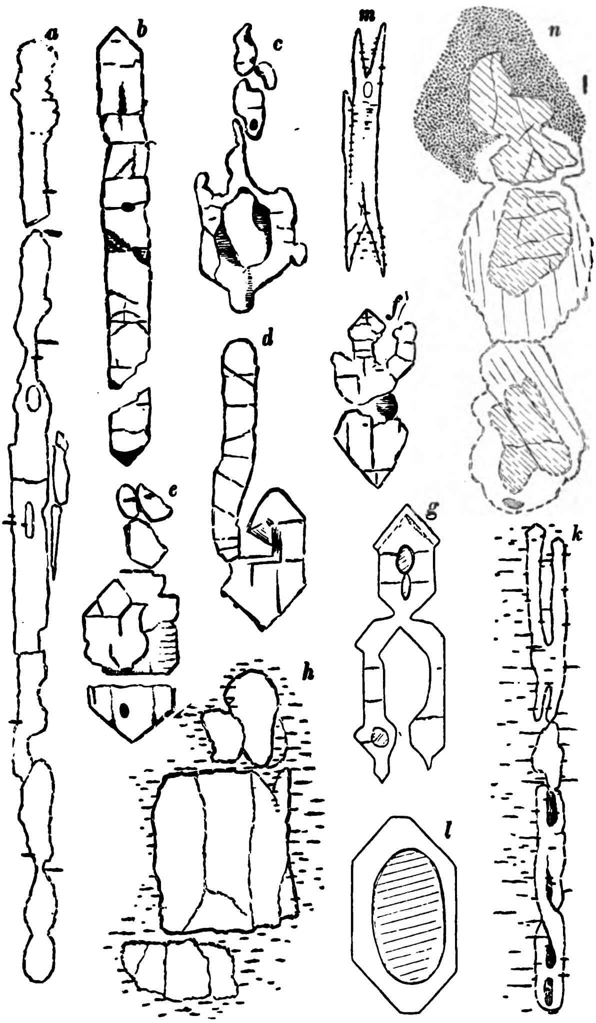
Occasionally the feldspar is present in larger forms; and more interesting to note is an occasional augite crystal (fig. 1, *b*) that evidently belongs to an earlier generation, and shows the distinct cleavage, and more or less also the crystalline outline of the species. The alteration to which this specimen, with others like it, has been subjected, and to which the red or purple color of the rock in the mass is due, has stained the iron red and reddened also the augite, although only exceptionally to such an extent as to make it opaque. The alteration spoken of may be simple weathering, although the occasional brick-red color rather suggests the action of hot water or steam; the feldspar remains perfectly clear and unchanged.

From the specimen described, which may be taken as the type, we pass to the coarser grained kinds on the one hand and to the very fine-grained on the other; both of these still retaining, however, the same general characters. A highly cellular specimen (74) with large vesicles, from the northwest brink of the crater, departs in general aspect most widely from the type; but, while relatively coarse-grained, it exhibits the same grouping though somewhat more rigid and geometrical, and shows even more clearly the mutual relations of the feldspar and augite. In the finer grained varieties (as 78) the augite sometimes predominates so largely that the whole becomes like a confused carpet pattern of interlacing arabesque forms, though here, when an individual form can be traced out, it has great beauty and perfection, branching and re-branching like some delicate forms of vegetation. Figure 1, *c* is an attempt to illustrate one of these forms, but it lacks the delicacy of the original. These forms consist almost exclusively of augite with very little feldspar. In another specimen of similar character a partial fluidal structure was noticed in the arrangement of the feldspar.

When the iron grains are only sparingly present and there has been no conspicuous alteration, the rock is of a light uniform gray, but the presence of iron in large amount makes it nearly black and obscures this structure; and when it and the augite are highly altered, the rock is a bright brick-red and in a section appears as a collection of nearly opaque red rosettes, the feldspar, however, still remaining clear. Glass is present occasionally, but usually in insignificant amounts, and for the most part it is nearly or quite absent. This feather-form of augite, which has been described, is not entirely confined to the clinkstone-like varieties of lava although eminently characteristic of them. It was occasionally noted more or less distinctly, in some other forms, especially the vesicular kinds to be mentioned later (p. 450) where it is seen in the minute second-generation augite which formed in the last process of consolidation. All the facts observed serve to connect its formation with rapid cooling.

Chrysolitic basalt.—The second group of rocks makes a very marked contrast with those just described. These are of coarse grain, often open-cellular, and very highly chryso-

4.



Chrysolite in part with orientated titanic iron; *a–f* (×55–60), from crystalline basalts of Mokuaweoweo. *g* (×75) from basaltic glass, Mokuaweoweo; *h* (×60) from Nanawale; *k* (×60) Kilauea; *l* (×100) crystal enclosing glass, Kilauea; *m* (×60), forked form, Maui: *n* (×60) portions of crystal enveloped by augite and clusters of magnetite grains, Maui.

litic; on this account the specific gravity is much higher, it varying from 3·00 to 3·20.* In many cases they have suffered some alteration which has given them a dull waxy surface, while the large grains of chrysolite are frequently iridescent and sometimes have an almost metallic luster. The color varies with the amount of iron oxidation from light gray to dull reddish gray or brown. The mineral constituents present are those of normal basalt; and most prominent among these is the chrysolite; in some specimens it must make up nearly half the mass of the rock; and in one case (102) probably more, this particular specimen having the unusual specific gravity of 3·20. The chrysolite was evidently early separated from the magma, and the changes of condition through which the lavas have passed is well shown in the irregularly corroded or occasional broken form of many of the crystals and grains. Even when there is a distinct crystalline outline, it is not a rare thing to find the crystal broken and the parts slightly separated. This is shown in the accompanying figures 4, *a* to *f*. Some of the corroded forms take very fantastic shapes. A novel and common feature of this chrysolite is the occurrence of very slender acicular forms. The length is often considerable, even when viewed macroscopically, in one case 2 to 3^{mm}, but in breadth they are often hardly more than a line, (note fig. 4, *a*.) This chrysolite shows the partial alteration alluded to in a broad rim of brown iron oxide; we can pass in the same slide from a crystal still preserving its transparency throughout, to those where only a string of chrysolite grains mark the position of the original individual, and from these to the cases where a narrow brown line of iron oxide alone is left; in a few cases (as 94) the chrysolite is stained bright red, showing that there has been oxidation of the iron without hydration.

The orientation of these peculiar rod-like forms, which are distinctly visible on a polished surface of the rock, is a matter of some interest. The fact that, in such a form as that of fig. 4, *b*, and others like it, the plane of the optic axes is transverse to the longitudinal direction and the bisectrix normal to the surface presented, shows that they are elongated in the direction of the vertical axis, the narrow dimension being that of the macrodiagonal. This chrysolite has often an unusually deep green color possibly connected with the partial alteration, and then shows distinct pleochroism with the absorption least in the direction of the vertical axis. It often shows spherical inclusions of a pale brown glass, sometimes arranged in parallel lines.

* Some of the separate determinations gave: 3·09, 3·18, 3·09, 3·04, 3·00, 3·20, 3·00.

The plagioclase feldspar is present in the ordinary forms, and shows no unusual features. The augite forms irregular grains crowded among the feldspars. Occasionally augite in larger more distinctly crystallized forms appears, evidently belonging to an earlier generation. This earlier augite shows the tendency, often observed, to cluster about the chrysolite grains. The titanic iron is not as a rule abundant, and for the most part appears in long slender rods often parallel among themselves over a limited area, and sometimes orientated by the chrysolite. In two or three of the specimens of this class the augite shows a tendency to assume the radiating form but this is the exception. Apatite is probably present in some sections, but only in small amount, and in most cases it was not detected. Glass is almost entirely absent from these rocks.

The occasional fractured character of the chrysolite has been spoken of; one specimen (90) shows this in an extreme degree, the chrysolite being separated here into many angular fragments for the most part showing no crystalline outline. The feldspar and augite individuals have also suffered in the same way and the ground mass has a curiously mottled microcrystalline structure suggestive of some porphyry. This specimen stands comparatively alone, although two or three others are of somewhat similar character.

Lavas with minute crystals of feldspar and augite in their cavities.—Allied to this second class of rocks just described, are a number of specimens which are interesting because of their remarkable crystalline structure. One of these (82) is a light gray rock with only occasional vesicles. It is, however, throughout open and porous with minute cavities into which project thin tabular crystals of feldspar seen distinctly with a strong hand-glass. A light yellowish augite is also observed, but the crystals are less distinct. Iridescent grains of chrysolite are scattered through the mass, and the fractured surface shows the same long lines of this mineral that are seen in the sections.

An interesting feature of this specimen and of others like it (including one very similar collected two or three hundred feet below the summit of the wall making the E.N.E. side of Kilauea, called Waldron's Ledge, also others from Makaopuhi) is the presence in cavities, of a mineral in very minute nearly spherical forms of a milk-white color. These are rather abundant through the mass of the rock, each little cavity containing one or two of them. They are so small (rarely more than ·2 or ·3^{mm} in diameter) that it is very difficult to determine their form, especially as the crystalline faces are dull and give almost no reflections. A hexagonal outline can usually be made out, and occasionally a triangular face through which the angle of another crystal sometimes projects, as if they were complex penetration twins, which the nearly spherical form also sug-

gests. Only one of these forms was detected in the thin sections, and the free side of this had a hexagonal outline, the whole being divided into sectors which alternately had like extinction, the surface of the sector being mottled in polarized light after the manner of some crystals showing anomalous optical double refraction. The fact that these little white spheres occur also on the inner glazed surface of the vesicles would seem to mark them of subsequent origin and hence probably zeolitic. Their form suggests a rhombohedral zeolite grouped like phacolite or the Australian herschelite. Two or three other zeolitic minerals were observed in isolated cases, but too sparingly and in too minute form to be satisfactorily identified.

In other specimens of this class (as 105, 107) the color is darkened because of slight alteration, the texture is coarser and the cavities larger. Here the clear glassy feldspar tablets are very distinct, and augite crystals, red or brown on the surface and opaque, also project into the cavities. Octahedrons of magnetite are often seen implanted upon the augite needles, and broad plates of titanic iron, with rhombohedral planes on the edges, sometimes attain a relatively large size. The feldspar tablets were here large enough to allow of their being separated and examined optically. In form they are either rhombic or acute triangular in outline, being bounded by the planes c (001) and y ($\bar{2}01$) or c and x ($\bar{1}01$), with the prisms very small when present at all. They can often be seen to be twins in accordance with the usual albite law. The extinction on the clinopinacoid made an angle of -14 to $-15°$ with the basal edge, which conforms to typical labradorite, as might have been anticipated. These highly crystalline specimens are also much like some of those collected from ejected masses about Kilauea, and they may here have had a similar origin.

All the specimens that have been thus far described were obtained with a single exception (No. 74 already located) either from the talus in the southern crater against the wall of the neck that joins it with the central pit, or else from the east side of the interior of central Mokuaweoweo. Nothing can be said in regard to the relations in place of the two types of basalt which have been described and which occur together at the points mentioned.

Other varieties of the lavas.—A number of the specimens cannot be classed in either of these two groups. They are light gray in color, not vesicular, and sparingly provided with chrysolite, if it is present at all, and characterized by a very uniform granular mixture of augite and plagioclase. A specimen taken from a vein in the western wall belongs here, also another stated to have come from the highest point on the edge of the crater. Still another specimen from the north brink is similar, but is porphyritic with patches of a glassy plagioclase.

Another group of specimens, differing in aspect widely from those described, although not essentially so in composition, are the highly vesicular kinds, sometimes coarsely vesicular and again with very minute cavities. They have for the most part a common character. Large grains of chrysolite are usually present, often very large in comparison with the size of the vesicles themselves, and with these also are sometimes large crystals of augite and feldspar, often grouped together. The ground-mass filling up the space between these first separated constituents is a dark fine-grained mass of plagioclase and augite with minute grains of iron sometimes so abundant as to render the whole nearly black and opaque. The augite sometimes shows a tendency to group itself in the radiating forms already described. A fluidal arrangement of the feldspar is the exception though occasionally observed in indistinct form. Only in rare cases is the whole mass of the rock made up of this fine-grained mass without the large crystals. A specimen from the source of the 1843 flow belongs here.

A specimen (76) which is described as the "ordinary ancient lava of the eastern brink of the crater" is a dark colored, coarsely vesicular rock (G.=3·00), with chrysolite abundant in large grains, and augite and feldspar also in large individuals, the amount of the fine-grained dark base of later formation is relatively small and the augite is somewhat radiated. A peculiar feature of the section is the inclusion by the augite of large plagioclase individuals not regularly orientated and giving the whole augite a peculiar mottled appearance.

Specimens of glass.—The Mauna Loa collection includes a large number of specimens of the scoria, many pumice-like specimens, some of them of extreme lightness and also specimens of glass. Several of the glassy kinds were examined microscopically. One of them (103) was a dense black compact mass uniformly glassy on one side, but on the other largely devitrified; the smooth surface of the glass was roughened by minute projections due to the chrysolite crystals. Its specific gravity is 2·91. Under the microscope the glass had a uniform brown color, and amorphous character, except for numerous minute doubly refracting points scattered through it. Here and there were clusters of small chrysolite crystals, having sharp outlines and perfectly clear except for occasional inclusions of the glass and minute black iron crystals.

A section cut transversely showed with great beauty the gradual transition from the amorphous glass to the largely devitrified lava. The pale yellow-brown glass of the border contained here and there elongated microlites, of dark brown color due to the glass immediately surrounding them, and also minute crystallites like those described below. In the inter-

mediate zone the microlites were more numerous and were surrounded by a brown oval aureole of somewhat deeper color than the rest of the glass, this having a beautiful spherulitic structure in polarized light. The nucleus was sometimes

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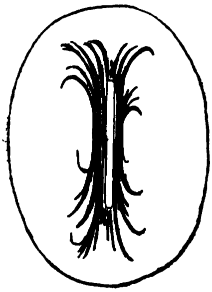

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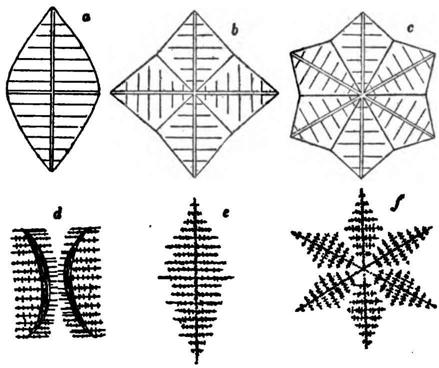


5. Feldspar microlite surrounded by dark filaments within an oval of brown glass (× 90).
6. Crystallites of various forms (× 160). All from basaltic glass, Mokuaweoweo.

transparent (feldspar) and about this were curious dark brown processes thrown off in curved lines (see fig. 5). The highly devitrified portion consisted of a nearly continuous mass of dark brown spherulites and crowded among them numbers of whitish nearly opaque crystallites. Many of the spherulites have a distinct nucleus of chrysolite or feldspar, and sometimes there is a medusa-like mass of dark brown bands radiating out from the nucleus.

The crystallites (see fig. 6) have sometimes a simple oval form with a faintly indicated structure transverse to the longitudinal axis; there are also compound forms with axes crossing at 90°, making a four-rayed star (*b*), or at 60° and these last when repeated making a regular six-rayed star (*c*). Rarely these forms are resolved into a delicate skeleton form of the types indicated (*d*, *e*, *f*) and of many other less regular shapes. Similar forms of "crystalloids" are figured by Vogelsang in plate VII of his work, "Die Krystalliten."

Chrysolite is distributed through the section in isolated crystals or in clusters. These crystals often enclose a considerable amount of the brown glass, and while sharp in outline have sometimes peculiar forms (fig. 4, *g*) which are interesting in connection with the corroded forms met with in the highly crystalline basalts which have already been described. Feldspar is present in the more highly devitrified portion; augite not

distinctly except as some of the microlites are to be referred to it.

Another specimen was lithoidal in character and showed throughout a distinct spherulitic structure. The nearly opaque spherulitic ground-mass contained many light brown transparent spherulites, and grains of chrysolite were scattered through as in the other.

Lava streams from Mauna Loa.—A considerable number of specimens are at hand from the streams of Mauna Loa of different dates, and taken from points at various altitudes. For the most part they are simply the surface scoriaceous portions and consequently without distinctive features. The flows of 1852, 1855–56, 1859 are thus represented. There are also specimens of the normal crystallized lavas of the stream, 1881, at Hilo; of that of 1843 taken from near its source which has been already alluded to, and of 1868, 1880–81, 1882 and 1887. These are all dark colored chrysolitic lavas, vesicular in a high degree, especially that from near Hilo (1881) and their characters are those of the vesicular forms spoken of on page 450. The specimens of the flows of 1868 are to be mentioned as particularly rich in chrysolite.

2. *Lava Stalactites from caves in the Mt. Loa lava streams.*

Perhaps the most interesting and remarkable formations connected with the lava flows from Mauna Loa are the delicate stalactites and stalagmites of lava which ornament the caverns. The specimens in the collection are mostly from a cavern in the lava stream of 1881, near Hilo, as described on page 109 of the last volume of this Journal. Figures of some of the forms of similar stalactites from the caverns of Kilauea are given by Brigham as more particularly mentioned later. They are of so great interest as to demand a minute description.

According to the accounts given, the flowing lava stream, crusted over at the surface, leaves behind it, when the molten material has flowed by, long caverns usually eight or ten feet in height, having a roof of one to three or more feet in thickness and a floor of the solidified lava. In the caverns are found hanging from the roof the slender lava stalactites. In the Hilo cavern they were from a few inches to twenty or thirty in length, and in some places only six to eight inches apart. The diameter, which seems to have been determined by the size of the drop of the liquid material, does not vary much, being usually about a quarter of an inch. Beneath the stalactites, from the floor below, rise the clustered groups of the stalagmites. These delicate forms are so fragile that they hardly bear transportation, and it is consequently difficult to preserve the longer specimens in their original form.

Through the kindness of Mr. Baker, the writer has received an admirable series of them, part of which are shown, one-third of the natural size, in the accompanying plate. These specimens were collected with great care and skilfully packed in moss and although fractured at many points when they arrived in New Haven, and thus divided into sections an inch or two in length, it was found possible to cement them together in their original positions.*

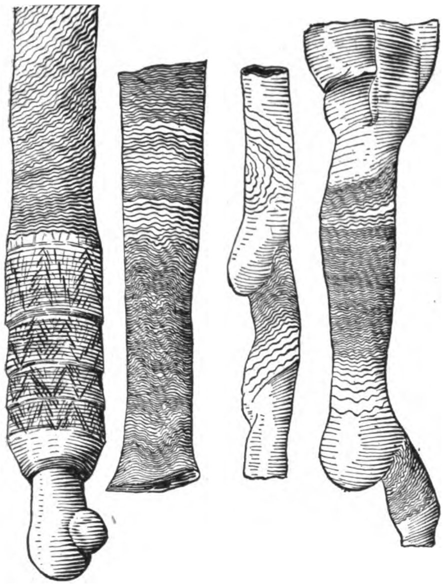
The general aspect of the stalactites and stalagmites is so well shown in the series of figures on plate XIV that but little description is needed. It will be noticed that while some are straight and nearly uniform, others are curiously gnarled and knotted, especially near their lower extremities. The end has often a little process thrown off at right angles, a little hook, or a close spiral of two or three turns often tangled or knotted together. The simple rods are usually round, not often flattened except when there is a sudden change in direction, when they may be pinched together like a glass tube bent when hot. The surface is exquisitely ornamented with most delicate markings. The stalagmites, formed by the droppings from above, are intricate clusters or piles of simple drops several inches in height as well represented in figures *a* and *b* on the plate.

The exterior of the stalactites has usually a more or less bright metallic luster, and, though sometimes dull and fine granular, the surface often reflects the light brilliantly from a multitude of crystalline facets; these sometimes separate into distinct scales, shown to be largely hematite by their reddish streak, though magnetite is also present. Minute rounded crystals, apparently also of hematite, are sprinkled often thickly over the surface. Sometimes the metallic covering is very thin, or is not continuous, forming patches on a brown surface. Occasionally at the ends it is altogether absent, and the exterior is thus brown and glassy in aspect, but still retains the polyhedral crystalline aspect; this glass-like crust polarizes light and is probably augite. Over portions of the rods—and in the case of the straight uniform ones (see the plate) over the whole length—the surface is transversely ribbed or corded in the most delicate manner. The beauty and perfection of these little ripplemarks, as seen under a hand-glass, are beyond description or adequate representation. They are parallel and symmetrical for a limited distance, but vary in fineness and form with every change in direction of the stalactite itself. Their flow is especially varied about each little projecting knob.

* For this skillful work as well as for the drawing of the plate, and of figs. 1–4 and 7, the writer is indebted to Dr. E. H. Barbour, recently of Yale University.

Figure 7 will give some idea of the transverse markings, but details of the structure can hardly be reproduced.

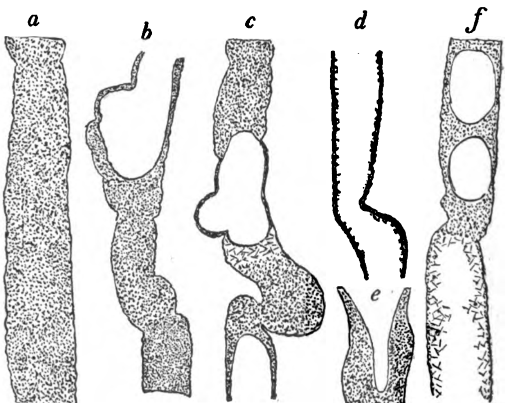
7.



Lava Stalactites, $\times \frac{1}{3}$.

The straighter portions of the stalactites are often solid throughout, though here and there they are hollow and consist of a mere shell; often portions that are perfectly solid alternate with the cellular parts, or the solid parts contain a series of large vesicles. Figure 8 gives longitudinal cross sections through a number of typical forms. In *f*, the lower cavity was thickly lined with crystals chiefly of feldspar. The exterior crust is seen in the cross section under the microscope to be very thin, and next to it comes usually a narrow, but not always continuous, band of augite with occasional iron crystals. The solid parts contain within very slender lath-shaped

8.

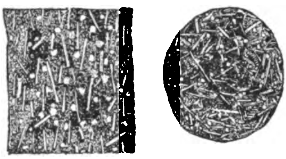


Longitudinal sections of lava stalactites in outline ($\times \frac{5}{4}$) showing open and solid portions, *a* solid and *d* open throughout, *d* with crystalline lining; the lower part of *f* is thickly lined with crystals, chiefly feldspar.

feldspars of a considerable relative length, often from $\frac{1}{4}$ to $\frac{1}{8}$ of the diameter of the stalactite, as seen in a longitudinal section. In one case they showed a marked tendency to parallelism with the axis of the stalactite, but in other cases this was less distinct. A partial concentric arrangement as seen in a transverse section was also noted. The feldspars often have black longitudinal inclusions probably of magnetite, and their cross sections, square or rectangular in outline, then have a large black center of the same form. A rather deeply colored greenish yellow augite, somewhat pleochroic, is packed in among the feldspars, and occasionally shows sharp crystalline outlines. There are also numerous grains and octahedrons of magnetite, and throughout a multitude of beautiful dendritic forms branching at angles of 90° or of 60°. This is one of the most marked characters of the sections. The areas, where these iron dendrites are crowded together, are less distinctly individualized, but no glass was noted. Chrysolite is also absent. Figures 9, *a* and *b* will convey some idea of the appearance of the longitudinal and transverse sections, though the relative amount of feldspar and augite is rather too small. The fact that the structure is throughout coarsely crystalline with the normal constituents of the basalt—except the chrysolite—is an important point.

9.

a. *b.*



Sections of lava-stalactites (×3), *a* longitudinal; *b* transverse.

The occasional cavities or open spaces in the solid parts of the stalactite are often beautifully lined with large rhombic tables of feldspar, perfectly clear, and so excessively thin as to suggest scales of mica; also dark needles of augite, often curved and wire-like, and octahedrons of magnetite. (See 8, *f*.) The feldspar plates have mostly the form of a symmetrical lozenge (fig. 10), with angles of 128° and 52°; one side is shown by the cleavage to be bounded by the basal plane, the other by the dome *x* (101̄). The extinction makes an angle of −7° to −9° with the basal edge which conforms to that of andesine, that is a plagioclase somewhat more acidic than that determined in the rock mass. These feldspar plates are often marked on the edges with a thin black scale, presumably magnetite, with numerous minute circular open spaces containing many black points as if the whole

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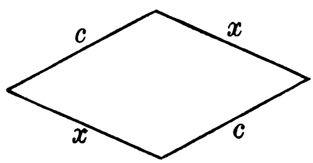


were formed by the drying of little bubbles. The augite crystals are often rough and black with magnetite.

Where there are vesicular cavities, often filling the whole interior of the tube, these are lined with a comparatively smooth, shining web of feldspar plates and clusters of brown augite crystals, or of augite needles alone, woven together like basket work. The dull surfaces of magnetite octahedrons are scattered abundantly among the augite and feldspar. The large quantity of magnetite is shown by the fact that the magnet picks up many of the fragments of the stalactites, even when quite large. The specific gravity of fragments of the solid portion of a stalactite was found to be 2·98.

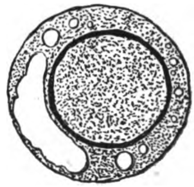
The explanation of the process by which these unique volcanic icicles have been formed is not easy to give. It is clear that further study, on the spot, of their occurrence and the circumstances of their growth is called for. It seems at first most easy to think of them as made by the rather rapid dripping of the semi-viscid lava from the roof. The evidence at hand, however, shows pretty conclusively that they could not have been the result of simple direct fusion. The fact that they hang down, from the solid crust, while the stalagmites formed by the dripping from above rise from the solid floor beneath, seems to prove that they were formed after the molten lava had passed by and the temperature had fallen below the point of fusion. If made directly from molten material, they could hardly be so perfectly crystalline throughout as they have been shown to be; we should expect to find them more like the glassy spatterings from the blow-holes of Kilauea mentioned on a later page. Moreover, the sorting out of the material is further evidence on the same side: the crystalline shell of hematite and magnetite, with its lining of augite, and within the solid crystalline mass, or the clusters of beautiful crystals chiefly of feldspar. Still again, the question has been raised as to whether the flow of a viscid liquid like the molten lava could form drops so small as the size of the stalactites show must have been present.

The fact that the lava rods or tubes of the stalactites are of nearly uniform size throughout their length, although bunched and knotted together at frequent points as has been described, is an important one.* It separates them, as to mode of origin, from the stalactites of a limestone cavern which form in a more or less conical shape from the flow down over the exterior surface of the lime-bearing solution. It seems to require that

* A stalactite from a Kilauea cavern collected by Prof. J. D. Dana is of interest here, since it forms an exception to those that have been described. About the first formed stalactite, with its rather thick magnetite shell (fig. 11) has been formed a second, somewhat vesicular and nearly concentric with it. This stalactite has the exterior coating of gypsum crystals spoken of by Brigham.

the shell should have formed first and that these tubes should have lengthened by the material carried down within them, finally resulting in their becoming solid to a greater or less extent. This is confirmed by the fact that the parts seemingly most solid often prove to have at the center minute crystal-lined cavities. The lengthening by the addition of material at the point of attachment above, the only other method that can be suggested, is difficult to conceive of.

11.



Transverse section of lava stalactite from Kilauea (×2) showing first formed stalactite within.

As the facts at hand are inconsistent with the theory of a direct formation from the melted condition, we are forced to speculate as to the power of the highly heated water vapor known to be present in large quantities, to form them from the roof by a sort of process of aqueo-fusion. This is a subject about which we know too little at present to make speculation very profitable, and the author prefers to drop the discussion here, in the hope that further observations may throw important light upon the matter. The experiments of Fouqué and Lévy in regard to the formation of basalt, with their important results, pursued the method of simple igneous fusion, and though Delesse and Daubrée have discussed the rôle of water in the formation of basalt and basaltic minerals, their investigations hardly seem to apply very closely to the present case.*

The fact that these stalactites occur also in the caverns of Kilauea has already been mentioned. Brigham describes them at some length, and although it is hardly possible to accept all his statements literally, especially as to rate and conditions of growth, his remarks are quoted here at length (l. c., pp. 462, 463):

"A formation which always excites the curiosity of visitors to Kilauea is found in many of the caves in the floor of the crater which have been undisturbed for several years. At first glance the tubes which hang from the roof and the curiously formed droppings beneath these, seem to be of igneous origin. An examination *in situ* shows that this was not the case. The roof of these caves is about two feet thick and generally unbroken; the stalactites do not occur under cracks and indeed there is often no fresh lava over the surface. The formative process may be clearly seen as the tubes form from day to day; and I have caught the steel-gray deposit in the drops on the end of the tubes upon my finger and watched its solidification. Usually the tubes are straight cylinders from one to three-eighths of an inch in

* Meunier has described the formation of chrysolite and of chondrules of enstatite, resembling those of meteorites, by the action of steam at ordinary pressures, with silicon chloride upon the red hot metal, C. R., xciii, 737, 1881.

diameter and sometimes more than two feet long. The bore is almost never continuous, and while externally they are smooth, within a mass of stony cells of considerable size is presented. As long as these tubes grow downward in the quiet upper region of the cave they hang perpendicularly, but when they reach farther down the currents of air and steam blow the deposits to one side and the tube becomes distorted; it may even return on itself. The drip in the bottom forms much thicker and more irregular stalagmites as will be seen from the figure which represents three actual forms not occurring, however, in the same cave. Specimens have been found which exceed eight inches in diameter and these are usually low and flat topped. The more slender ones sometimes rise to a height of two feet; and so rapidly is the silica deposited that they seldom increase in diameter but are true acrogens, none of the suspended silica running down the sides. In one cave the growth of the stalactites was at about the rate of an inch a week but owing to the varying amount of water or steam the production is quite irregular. They are often coated with beautiful white crystals of gypsum, sometimes tipped with needle-like transparent crystals of the same mineral when the cave is high. The natives collect them with the upper open joint of a long bambu."

The following analysis of the solid stalactite, by John C. Jackson, is given by Brigham:

	SiO_2	Al_2O_3	Fe_2O_3	MnO	CaO	MgO	Na_2O	K_2O
G. = 2·9	51·9	13·4	15·5	0·8	9·6	4·8	3·0	1·1=100·1

3. *Lavas of Kilauea.*

The specimens in hand from the volcano of Kilauea, which have been examined microscopically, include four specimens (12, 16, 17, 18) of the recent lava from the bottom of the crater, six specimens of the older lavas, two (13, 15) from Waldron's ledge on the northeast side and four (14, 19, 20, 26) from the wall west of Halemaumau; finally a number (1–11) from the ejected masses on the borders of the crater, especially on the west side. There are also a number of glassy and scoriaceous kinds.

1. *The recent lavas.*—The specimens of the recent lavas were taken from the stony part of the layer below the inch or more of glassy crust. They are dark colored, vesicular basalts, containing chrysolite but not in very large amount. The irregular grains of chrysolite are often aggregated together with augite crystals and to a limited extent with the lath-shaped feldspars, these constituents obviously representing those which first separated from the magma. The mass of the solid portion of the rock is of uniform character, consisting of augite and feldspar with the interstices between them black with the crowded grains or plates of magnetic and titanic iron;

about the borders of the vesicles the iron is especially dense. It is very interesting to note that these specimens are the only ones among those from Kilauea which show distinctly the stellate feather-like forms of the augite and feldspar so characteristic of many of the Mauna Loa lavas (as shown in fig. 1, *d*, p. 443). The augite forms here are usually smaller, and less varied, but there is the same grouping in parallel bundles diverging off at the ends into dendritic forms. The association between the augite and feldspar is also very close, as if the crystallization of the two had been almost simultaneous. Thus the feldspar not only forms in some cases the outer extremities of the feather but sometimes also is a central rib flanked on both sides by the augite.

Occasionally the chrysolite appears in the long slender forms noted as common among the Mauna Loa lavas. One of these is shown in figure 4, *k*, which also exhibits the peculiar feature of many of these rocks—often noted in other regions*—the grouping of the titanic iron in parallel position about the chrysolite, normal to the vertical axis. An arrangement of the elongated forms of the titanic iron in parallel position over small areas is sometimes noted where there is no evident relation to the other constituents. Usually, however, the chrysolite is the controlling influence and the individual often bristles with these little iron rods about its whole outline as seen in the section. Although these specimens were taken from so near the glassy crust there is little or no glass shown in the thin section. A specimen from the bottom of the Little Beggar, the lowest part of Kilauea, shows very considerable alteration, the surface being covered and the vesicles filled with crystals of gypsum; the mass is rendered red and nearly opaque by the oxidation of the iron.

A specimen of partially devitrified glass shows the presence of spherulites, like those mentioned in similar specimens from Mauna Loa, increasing in number where the devitrification is most complete. Crystals of chrysolite and microlites of feldspar are also present in large numbers. Some curious specimens from the spatterings about a blow-hole exhibit a vesicular glass with crystals of chrysolite and aggregates of augite and feldspar. The chrysolite encloses large amounts of glass, often in curiously arranged symmetrical bands. One of the crystals is represented in fig. 4, *l*.

2. *The older lavas.*—Of the ancient Kilauea lavas, one specimen from Waldron's Ledge (13) is remarkable for its highly chrysolitic character, as its unusual density (G.=3·18) well shows. It is a grayish compact rock thickly sprinkled with greenish yellow chrysolite grains. Under the microscope the chrysolite is seen to be in large individuals, usually irregular

* Cf. Rosenbusch, Mass. Gesteine, p. 722, 1887.

grains, though also in indistinct crystals and occasional rod-like forms. These often contain abundant glass inclusions. The grains are often packed about with a poorly defined border of augite and it is in this zone particularly that the little rods of titanic iron are regularly orientated, standing out from the chrysolite in the manner already described. Besides this, it is a granular mixture of augite and plagioclase not showing any glass. The other specimen (15), from the foot of Waldron's Ledge, is a light-gray cellular rock, highly crystalline, the minute cavities lined by plates of feldspar and tables of titanic iron. It is much like some of the specimens described from Mauna Loa (p. 448), and with them is characterized by the same milk-white spherical mineral in the cavities, provisionally referred to phacolite.

The lavas from the west wall of Kilauea west of Halemaumau are all closely similar in character among themselves; they are dark-gray in color, vesicular, and contain a fair amount of chrysolite. The structure is throughout crystalline, rather coarsely granular, and the chrysolite is marked by its usual bristling border of titanic iron. One or two of these show something of the radiating augite forms.

3. *Ejected masses on the border of Kilauea.*—The specimens from the borders of Kilauea are supposed to have been ejected at an explosive eruption about a century since. The larger part of the masses are described by Professor J. D. Dana as being of a fine-grained, gray, slightly vesicular lava. Other specimens* are reddish or chocolate-colored, coarsely granular and highly crystalline. In the latter, the chrysolite is present in very large amount and has suffered from alteration, probably by the action of heated water vapors, so that the fractured surface is either dull-red and opaque or else slightly iridescent. The feldspar crystals are clear and glassy, and where there are cavities they often project in distinct transparent plates from the walls. The crystals have an angle of extinction of $-14°$ with the b/c edge, and hence conform to labradorite, like those of similar occurrence among the Mauna Loa specimens. Under the microscope the chrysolite is seen to be surrounded with a deep-red border, and the iron oxidation has penetrated into the mass of the crystal sometimes along broad fracture-lines, and more generally in a network of fine wavy lines giving it a peculiar feathery aspect. Not infrequently the oxidation has gone so far that the chrysolite is perfectly opaque and by reflected light is bright brick-red.

Specimens 6, 7, 9† are examples of the light-gray lavas but of peculiar characters. No. 9 is a light-gray rock conspicuous among all those under examination for its beautiful crystalline

* Here belong Nos. 3, 8 with G.=3·18, 10 with G.=3·15.

† For 6, G.=3·15; for 9, G.=3·10.

structure. It is very light and porous and in each little cavity there are groups of crystals of feldspar in the usual rhombic plates, with minute slender needles of a pale yellow augite iridescent on the surface, and thick tables of titanic iron showing large rhombohedral planes ($cr=56°$). These last have bright faces, often cavernous, and with a bluish steel-like tarnish. The augites are flattened parallel to the orthopinacoid, as shown by the parallel extinction and the oblique optic axis. Chrysolite is present in the mass of the rock but hardly appears in the sections.

No. 7 is a similar rock, but more compact except for parallel lines of cavities partially filled with black glass. No. 6 shows the same structure in part, but the mass of the specimen has a base of a very black glass with crystals of feldspar, augite, and broad plates of titanic iron running through it. In the large cavities the crystals of these minerals project out, though the surface of the cavity is lined with a glassy web. One of the sections under examination is cut across the junction and shows both the uniform fine-grained crystalline portion and the glassy part with its large enclosed crystals. A curious feature of the glass is the presence of a swarm of minute apatite needles running through it in every direction. These do not extend into the crystallized parts. Apatite usually appears as one of the very earliest secretions from the magma, and why it should be thus localized in these patches of glass while absent from the crystalline parts of the rock, it is difficult to explain. In general, apatite has been found to be a rare constituent of the Hawaiian lavas.

Two others of the specimens (4, 7) are gray compact rocks extremely fine-grained except for occasional chrysolite grains. No. 1 is peculiar in having small uniformly-distributed patches of a dark colored slightly opalescent glass, which is deep brown and nearly opaque in the thin section except as it is penetrated by apatite needles which here also are confined to it.

With the specimen from Kilauea proper belong those collected by Mr. Baker from Nanawale and Makaopuhi, the former chiefly remarkable for their chrysolitic character, the latter sparingly so. Several of the latter specimens are remarkable for that crystalline structure that has been several times remarked upon, and one of them contains the white zeolitic mineral.

Former observers have dwelt at length upon the features of the glassy forms of the lava and the presence of glass in the partly crystalline varieties. This is probably to be explained by the fact that the specimens which first present themselves to the collector on his visit to the interior of Kilauea are the superficial more or less scoriaceous or glassy forms which constitute merely a crust and do not represent the true character of the average lavas. The writer has found glass only a com-

paratively insignificant element in the normal rocks and *often wholly absent*, even from those of recent eruption.

4. *Relation between the rocks of the Summit crater of Mauna Loa and those of Kilauea.*

In general, the lavas of the summit crater and of Kilauea, so far as examined by the writer, are strikingly similar in character, all being augitic basalts, varying chiefly as regards the amount of chrysolite present. The clinkstone-like rock of Mokuaweoweo has not been observed at Kilauea; but the feathery grouping of augite and feldspar which characterizes it belongs to the recent Kilauea lavas as well. The darker colored vesicular basalts, which are highly chrysolitic and hence of high specific gravity, are alike from both craters. Writers on volcanoes have attempted to draw conclusions in regard to the distribution of the heavier and lighter lavas according to altitude, limiting the former to the lower levels. This is a natural inference on *a priori* grounds, but it does not rest on observation as the facts already stated sufficiently show. It is a striking fact in connection with the mechanics of volcanic eruptions that lavas of the heaviest character (3·15 and 3·20) should have been raised to an altitude of nearly 14,000 feet above sea-level.

The chemical composition* of the Kilauea lavas is well shown by the series of analyses (14 in number,) given by Silvestri, and also those—chiefly of glassy forms—given by Cohen.

Of these analyses, three by Silvestri, (A, B, C), and two by Cohen (D, E), are quoted here, viz:—

A. Recent vitreous basalt, fresh and unaltered.
B. Older basalt, also fresh;
C. Older basalt, much altered;
D. Compact basalt-obsidian;
E. Pele's Hair:

	A.	B.	C.	D.	E.
	G.=2·97	G.=3·01	G.=2·80	G.=2·75	G.=2·66
SiO_2	49·20	48·82	48·60	53·81	50·82
TiO_2	1·72	1·16	----	2·01	*undet.*
Al_2O_3	14·90	15·22	25·45	13·48	9·14
Fe_2O_3	4·51	5·72	17·55	3·02	7·33
FeO	12·75	9·65	1·20	7·39	7·03
MnO	0·28	0·67	*tr.*	*tr.*	0·38
CaO	9·20	10·40	2·20	10·34	11·63
MgO	3·90	4·55	0·98	6·46	7·22
Na_2O	1·96	2·10	1·38	3·23	1·02
K_2O	0·95	0·90		0·64	3·06
P_2O_5	0·42	*tr.*	*tr.*	----	----
H_2O	0·10	----	1·87	0·57	1·74
	99·89	99·19	99·23	100·95	99·37

* The remark made by Professor J. D. Dana must be repeated here that the early analyses published in the Geological Report of the U. S. Exploring Expedition, having been made for him by an inexperienced analyst, are entirely unreliable and should not be quoted.

Of other specimens from the island of Hawaii there are two specimens from Punaluu, one from the outside of a bomb and the other from an *a-a* flow. The interesting point about these is the strongly accentuated flow structure as shown in the feldspar microlites as they find their way around the occasional large crystals of chrysolite and augite—the fluidal character is as a rule entirely absent from the specimens before described, and in general is not so common in basic as in acidic lavas.

Specimens from western and northwestern Hawaii, Kawaihae and Mahukono are again more or less vesicular chrysolitic basalts. Of these rocks that from Kawaihae is the most noteworthy because of the large clusters of glassy feldspar crystals which give it a striking porphyritic aspect.

5. *Lavas of Maui.*

From the island of Maui about a dozen specimens have been subjected to microscopical examination, of which three were collected by Rev. S. E. Bishop. The most recent lavas of Haleakala are represented by three specimens, all somewhat scoriaceous. One of these is from the summit at an altitude of nearly 10,000 feet, the others from the bottom floor. They are all very highly chrysolitic, and of high specific gravity (G.=3·10). The similarity of the hand specimens is so great that they might almost have been taken from the same block. They are dark colored, very vesicular, and highly porphyritic with both chrysolite and augite. The large and well-formed crystals of augite often have a narrow external zone of deeper color (violet-brown) and are distinctly pleochroic. They are usually mottled with inclusions of glass or iron. The chrysolite shows but few inclusions. The ground mass is thickly sprinkled with iron grains making it nearly opaque; small triclinic feldspar needles and a secondary augite in minute form are seen. In these specimens the feldspar must make up but a very inconsiderable proportion of the whole. These recent chrysolitic basalts in Haleakala are much more porphyritic and otherwise quite different from the basalts of Mauna Loa and Kilauea.

More different still are several specimens of the older lavas. One of these (29) is from within the crater. It is a very fine-grained, dark bluish gray rock of uniform texture, perfectly fresh and showing but few minute cavities. It is a feldspathic rock presenting under the microscope a rather confused aggregation of feldspar and augite, the latter in minute grains, the whole thickly sprinkled with grains of iron. Chrysolite is occasionally noted in peculiar elongated forms, generally forked at both ends, and having a border of titanic iron grains as before noted (fig. 4, *m*). The most marked peculiarity is

the presence of minute scales of a dark brown mineral, probably biotite, which, however, is only present very sparingly.

Another interesting specimen (30) which was obtained from the top of Haleakala is a thin, almost schistose rock, light gray in color and presenting the same sort of an aggregation of feldspar and augite under the microscope. Chrysolite, however, is a prominent constituent especially in the hand specimen. There are also large elongated but usually ill-defined aggregates of magnetite grains marking the presence of original large individuals, biotite or hornblende, which have been re-absorbed into the magma. Occasional remnants of the original mineral are noted but in very small amount. Another curious feature of this rock is the presence of a zone of augite about the grains of chrysolite. One case of this is illustrated by fig. 4, *n*. The chrysolite crystal though separated into different parts has throughout the same optical orientation as indicated by the shading, while that of the augite varies from grain to grain. The mantle of magnetite grains about the upper end of the chrysolite seems to represent the remains of the augite which has disappeared. This re-absorption of augite is not commonly observed, but this case, and still more another one where of a single augite crystal alone a large part has disappeared in this way, places the matter above doubt. This zonal arrangement of the augite about the chrysolite has been noted by other observers in a number of cases.*

The structure and composition of both these last mentioned rocks suggest that they should perhaps be classed among the augite-andesites rather than the basalts. To decide this point we have the silica determinations, for which I am indebted to Mr. Henry L. Wheeler of the Sheffield Scientific School. He found in the first (No. 29) 48·42 p. c. SiO_2, and in the other 50·44 p. c., which conform to that of normal basalt.

The remaining specimen from the top of Haleakala is a dark gray, almost black, rock of the finest grain, very compact and breaking with a conchoidal fracture. It is characterized by the large amount of iron in minute grains very thickly distributed, so as to make the section nearly opaque unless extremely thin. The feldspar microlites are the most prominent constituent, and these show a rather distinct fluidal arrangement. The two specimens from Paia on Maui are much like those from Haleakala just mentioned, especially No. 29, and like it they bear the same resemblance to andesite. A curious point about them, is their readiness to alter, the exposed surfaces passing into a soft earthy mass of a light brown color.

The specimens from Western Maui, collected by Rev. S. E. Bishop, are rocks of peculiar and interesting character. Mr.

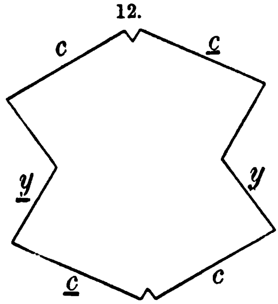
* See F. D. Adams, Amer. Naturalist, 1087, 1885, G. H. Williams, this Journal, xxxi, 35, 1886.

Bishop says that they are "crusts and soft interiors of the same formation (apparently flowing lava) found on Launiupoko hill, 3 miles S. of Lahaina. A precisely similar formation occupies the front of Mt. Ball, 2½ miles above Lahaina. The crusts are often rolled under the gray, soft material. Many crusts of grotesque form lie about, from which the softer part has been washed away. Many portions of the gray, soft mass are of great thickness. Much building stone has been hewn from it. It presents no appearances of being the result of any decay, being compact and of uniform texture, except the hard crusts, many of which are crumpled up as if in flowing, like pahoehoe."

One of the specimens (28) is a whitish gray compact rock, whose surface is worn out into a series of deep holes between projecting ridges nearly one inch in height. The texture, though appearing closely compact at first sight, is seen by the glass to be minutely porous, and the surface is speckled with very small rusty spots. Under the microscope it is seen to consist almost exclusively of plagioclase, here and there porphyritically developed; there are also the remnants of a bright green pleochroic mineral present in traces only and obviously the original mineral whose disappearance has left the rusty spots; it seems to be hornblende. A little biotite is also present. Iron is scattered through the mass rather sparingly in minute grains; no augite was noted. Another specimen shows the transition from the firm rock to a soft chalky condition powdering under the fingers. The section is very like the other just described, though the feldspar is much clouded and an occasional red crystal of chrysolite is noted.

A third specimen (32) is a flake from a large bowlder (8×5 ×4 feet) found one mile S. W. of the summit of Mt. Ball. Mr. Bishop remarks that, in the eroded cliff, bowlders occur cemented by mud, being ejectamenta from Mt. Ball. The specimen is finely schistose and so soft and friable as to separate easily into thin silvery scales, and by handling it is soon reduced to a fine powder. Microscopic examination shows it to be very nearly the same in material with the others, but having a distinctly fragmental appearance. There is more chrysolite present in small broken fragments of crystals; there is also a little brown biotite in scales. The mass is made up of penetration twins of plagioclase according to the Carlsbad law mostly arranged parallel to

12.



the brachypinacoid and hence showing no other kind of twinning. The form of one of these groups is shown in fig. 12. The cleavage marks the position of the basal plane and the angle of the section (about 80°) shows that it is bounded by the planes *c* (001) and *y* ($\bar{2}$01). The extinction makes an angle of a few degrees with the basal edge, varying + or − with a slight change in the direction of the section. This optical character and the further fact that the acute bisectrix is nearly normal to the brachypinacoid would make the feldspar an oligoclase. Occasional feldspar individuals are cut more nearly parallel to the basal plane and have the usual elongated form, and show the twinning like the other specimen, but as a rule they all lie nearly parallel to the brachypinacoid. The amount of silica present, as determined by Mr. Wheeler, is 61·63 p. c., which corresponds to the microscopic determination. This remarkable feldspathic andesite is a totally different rock from any other which has been as yet obtained from the islands, and the writer hopes to be in the position later to give a more minute account of its occurrence and composition.

5. *Lavas of Oahu.*

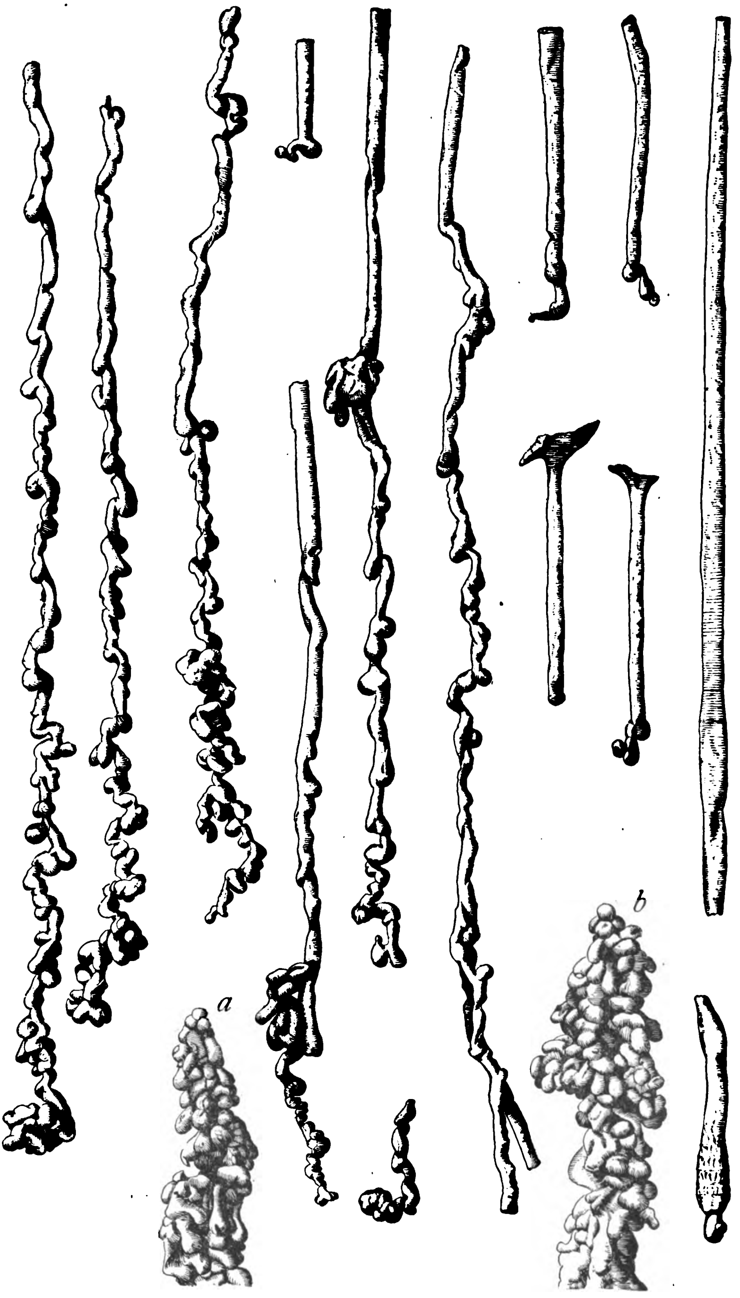
Of the specimens in hand from the island of Oahu, six (33, 36, 40, 41, 44, 45) are from the Kaliuwaa valley, near Punaluu on the north side of the island; four (27, 38, 39, 43) are from the Waialua plain; one (42) from a point just north of Kahuku Bluff; another (37) from a gulch beyond Monolua, 4 miles west of Honolulu; and, finally, there are a number of specimens of the tufa from the Punchbowl near Honolulu. Among these specimens, two are forms of highly chrysolitic basalts; these are the specimens from Kahuku Bluff and one of those from near Waialua. In the first of these (42) the chrysolite makes up probably two-thirds of the mass of the rock; it is present in distinct isolated crystals, having the characteristic form, each crystal having a rather broad, rusty border, though the interior is for the most part clear and unchanged. The chrysolite incloses grains of iron, but very little glass. The ground mass is a fine-grained mixture of augite and plagioclase with considerable iron, the augite being the more prominent constituent.

In the specimen from Waialua (43) the chrysolite is also prominent; its specific gravity is 3·06. With the chrysolite, the augite and feldspar also occur in large individuals besides being present in the base. The feldspar here contains dark-colored glassy inclusions in large numbers arranged parallel to the vertical axis. The base is a confused mixture of dirty brown augite and feldspar, with iron in considerable amount. The specimen (33) from a dike in the upper part of the Kal-

iuwaa Valley is a very compact, nearly black basalt, unusual in showing occasional grains of pyrite. The feldspar is fresh, but the augite is more or less altered and its place taken by a serpentinous substance, while occasional cavities are filled with a light colored radiating zeolitic mineral showing feeble double refraction. Besides the usual magnetic iron, which is scattered through in grains or octahedral crystals, there are also curious aggregations of iron ore in very slender rod-like forms, sometimes crossing each other at right angles, but usually matted together with a confusedly reticulated structure, sometimes forming nearly opaque spherical aggregates. Specific gravity 2·90.

Chrysolite is present very sparingly in the remaining rocks, the hand specimen showing only here and there an isolated grain, and sometimes close search is needed to detect it. They are all light bluish gray basalts, with specific gravity ranging from 2·86 to 2·91. No very close study has been made of these specimens, but with a number of them their aspect, their highly felspathic character, and the microscopic structure, made it seem as if they might more properly belong to the andesites; a silica determination of one of them (36, G.=2·86) by Mr. Wheeler gave, however, only 50·55 p. c. SiO_2. Several of these rocks show more or less alteration, and in one of them (36) the occasional crystals of chrysolite have entirely passed into serpentine. For the most part they are highly crystalline, but one of the group (45, G.=2·88) is exceptional in showing numerous patches of a dark brown glass; this specimen is the most highly chrysolitic of the number, it being present in minute grains among the feldspar and augite, each grain having its orientated fringe of titanic iron. No nepheline basalt was detected among the specimens in hand.

Résumé.—The chief points brought out and discussed in the preceding pages are, the characters of the clinkstone-like basalt with its novel forms of feather-augite, and also of the heavy chrysolitic basalt, each from the summit crater; the general similarity between the lavas of Mauna Loa and of Kilauea and the crystalline character of both, even of the recent forms; the structure and origin of the stalactites in the caverns of the Mauna Loa lava stream, like those in the caverns of Kilauea, offering new problems in the formation of igneous rocks. It is shown further that the lavas in hand from Maui—with the exception of the andesite from the western part of the island—and also those from Oahu, belong to the basaltic type, though often approaching andesite in appearance; furthermore, that the lavas of Hawaii show extensive alteration but only so far as the iron oxidation is concerned, while some of those of Maui and Oahu, especially the latter, are much more profoundly changed.



STALACTITES FROM LAVA CAVERNS NEAR HILO ($\frac{1}{8}$).